The Implications of Trade and Offshoring for Growth and Wages

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STOCKHOLM SCHOOL OF ECONOMICS

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Preface

This report is a result of a research project carried out at the Department of Economics at the Stockholm School of Economics (SSE).

This volume is submitted as a doctor's thesis at SSE. The author has been entirely free to conduct and present his research in his own ways as an expression of his own ideas.

SSE is grateful for the financial support which has made it possible to fulfill the project.

Filip Wijkström
Associate Professor
SSE Director of Research

To Natalia

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Contents

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Stockholm, September 2011

Damián Migueles Ch.

Summary of Thesis

In their pursuit of profits, adventure and new markets, humans have traded since prehistoric times. The relations between trade, profits and technological change, however, were not the main concern of early economists ranging from Aristotle to the mercantilists. Presumably because in their world, the rate of technological change was decidedly low, and the basket and quality of goods available through production and trade did not change much over decades, or even centuries! In addition, it was not the technological change that brought markets closer, but *"the ferocity of nomadic horsemen or the edge of a scimitar"*, while *"violently imposed monopolies and plunder"* (Findlay and O'Rourke, 2003) made trade more profitable.

It was not until the industrial revolution that growth rates began to rise to high levels. Now that human inventions and discoveries came faster and cheaper than ever, trade liberalization was not only the way to gain access to new markets; trade liberalization had also a role in promoting growth. Trade liberalization in the form of lower trade costs, increases profits from exporting, and consequently, overall profits. That increases the incentives to innovate, produce something new and export it. Trade liberalization thus promotes technological change by increasing the incentives firms have to conduct R&D, implement the innovation or improvement and make larger profits. The field of economics that studies economic growth as the result of decisions made by profit-maximizing firms is called endogenous growth theory. There have been a number of theoretical advances in endogenous growth theory over the last 20 years, but there is no consensus on whether trade liberalization promotes growth or not. Some models predict that trade liberalization has a positive effect on growth. Other models predict no effect at all. In addition, not all countries have benefited equally from globalization.

In this dissertation, I study the linkages between trade liberalization and economic growth (papers one and two). In papers two and three, I also explore the relationships between globalization, growth and the demand for labor. There is well documented evidence from a number of countries, that the demand for less-skilled labor has decreased in recent decades, and this decrease has resulted in a higher skilled-wage premium, that is, the degree in which the wages of skilled workers exceed less-skilled worker wages. This phenomenon has occurred in several countries, including the U.S. The skilled-wage premium has also increased in Europe, although less dramatically. In paper two, the relationships between trade liberalization, growth and wage inequality are analyzed using an endogenous growth model. The third and final paper is an empirical study on the relationships between the demand for labor and offshoring. More specifically, I examine what happens to the demand for different types of labor (not only skilled and unskilled labor) in the Swedish plants of Swedish multinational enterprises, when these multinationals expand abroad.

Summary of Papers

Paper 1: When Does Trade Liberalization Promote Economic Growth?

Within the endogenous growth literature, there are two papers that early emphasized the relationship between trade and growth, one is Baldwin and Forslid (2000) and the other is Dinopoulos and Segerstrom (1999). In the paper of Dinopoulos and Segerstrom, the different channels through which trade promotes growth are analyzed. They show that trade liberalization can stimulate growth via a pro-competitive effect in the R&D sector and/or the financial sector. Baldwin and Forslid, on the other hand, find that trade liberalization has no impact on growth. What distinguishes one model fundamentally from the other is that Baldwin and Forslid assume that innovation takes the form of new varieties entering the market (horizontal innovation) while Dinopoulos and Segerstrom assume that innovation is vertical and takes the form of firms improving upon the quality of existing products (a vertical innovation "quality-ladder" model). Thus, trade liberalization in the models of Dinopoulos and Segerstrom (1999) and Baldwin and Forslid (2000) generates an unexplained puzzling result: trade promotes economic growth if innovations are vertical but has no effect on growth if innovations are horizontal. I find that result to be puzzling because there is neither a formal nor an intuitive explanation for such a significant difference, just based on the type of innovation.

Recent developments within the endogenous growth and trade literature seem to provide robustness to this dichotomous puzzling result: Trade liberalization has no (or ambiguous) effects on growth when innovation is horizontal (new varieties), but promotes economic growth when innovation is vertical (better qualities).

In this paper, I show that whether innovations are vertical or horizontal is not relevant for explaining and solving the puzzle presented here. I show that the underlying assumptions about intellectual property rights (IPRs) implicit in the widely used versions of the horizontal and vertical innovation EGMs are what determine whether trade liberalization promotes growth or not.

Paper 2: Trade With Heterogenous Firms and Workers

Trade has not been in the last decade the most accepted transmission channel for analyzing wage dispersion. One reason being that the predictions of the Stolper-Samuelson theorem are at odds with the empirical evidence. This theorem states that a decline in the relative price of a good reduces the return of the factor used intensively in its production. In a North-South trade scenario with skilled-labor intensive industries in the North and unskilled-labor intensive industries in the South, the

Stolper-Samuelson mechanism implies that increased trade between these two regions puts downward pressure on the relative wage of unskilled workers in the North. The evidence, however, shows that trade between advanced and less advanced countries is limited. Moreover, for this mechanism to work, trade must induce changes in the relative prices of the goods produced by skilled and unskilled-labor intensive industries, and in the U.S., for instance, there is evidence showing that U.S. domestic relative prices (of imported in terms of exported goods) are roughly constant, in spite of increasing volumes of trade.

One of the first models that reconciles the empirical evidence with a theory of international trade is Dinopoulos and Segerstrom (1999). They propose a quality-ladders endogenous growth model with trade with a Schumpeterian creative-destruction mechanism that makes old products obsolete and encourages firms to do costly skilled-labor intensive R&D. In their model, trade liberalization increases the potential profits from exporting and makes innovations more profitable, which in turn increases the demand for resources in the R&D sector. However, all producing firms are identical, and they could, therefore, not account for the firm heterogeneity found in empirical work. They also assume that successful innovations are always exported and leave fixed costs for producing and exporting out of their analysis, underestimating the costs involved in production and exporting activities.

The new-new trade literature, pioneered by Melitz (2003), has put focus on intra-industry firm heterogeneity and fixed costs involved in production and trade, successfully accounting for many new firm-level empirical facts. Those models, however, have typically worked with one factor only; being unable to address questions on wage inequality. Models with more than one factor use Heckscher-Ohlin-Samuelson or Ricardian frameworks and have not managed to keep domestic prices constant when trade costs fall.

In this paper, I introduce the role of trade openness as a cause for wage dispersion in the new-new trade literature, and I show that this can be done without affecting the relative prices of traded final goods. In contrast to the aforementioned new-new trade literature that is "static" with zero productivity growth rate in steady-state, the model presented here is dynamic, allowing me to study the impact trade liberalization has on the growth rate of the economy. Another distinguishing feature is that here, trade is not driven by differences in factor endowments or in unit labor requirements; instead, the direction of trade will be determined by financial markets and successful R&D efforts. The model also generates results that are already established empirical facts. The main results of this paper are twofold: *i)* trade liberalization increases wage inequality, although the effect globalization might have on the skilled-wage premium cannot account for all of its increase, and *ii)* trade liberalization contributes to general skill upgrading in the economy. These results are derived for the first time from a Melitz-type model where all the standard results of the new-new trade literature hold.

Paper 3: Offshoring and the Onshore Composition of Tasks in Swedish Multinationals

In the final paper, I study the relationship between globalization and the demand for labor, but from a different angle. I investigate what happens to the demand for different types of labor (not only skilled and unskilled labor) in the Swedish plants of Swedish multinational enterprises, when these multinationals expand abroad.

Increased reallocation to other countries of some parts of a firm's activity (offshoring) has created a strong interest in how a transfer of production abroad affects the demand for different types of labor. The traditional division into skilled and unskilled labor for analyzing the impact of offshoring has recently been challenged. Many authors claim that the nature of the performed task may be more relevant for the job's propensity to be offshored than its skill level (see e.g. Leamer and Storper, 2001; Markusen, 2005 and Blinder, 2006). For instance, a highly routinized task, which can easily be codified, is more likely to be offshored than a task that requires tacit information, regardless of the skills of the worker (Leamer and Storper, 2001). Similarly, a task that neither needs to interact with other tasks nor needs to be within certain geographic proximity is also more easily offshored. Interpreting X-ray pictures is an example of such a task that is sometimes offshored but is also skill-intensive. Maintenance work, on the other hand, is highly interactive with the maintained facilities and, therefore, less easily offshored, although it is less skill-intensive. According to this idea, I classify tasks according to the degree to which they are routine and interactive. The ex-ante hypothesis I had was that routine and non-interactive tasks would be offshored to a larger extent when Swedish multinationals expand abroad, especially when offshoring to produce inputs used by Swedish plants (vertical foreign direct investment), typically at lower costs. Instead, I found that when Swedish multinationals expand offshore in order to get better market access (horizontal foreign direct investment), the cost shares of the labor force that performs non-routine and interactive tasks in a Swedish plant decrease. This relationship seems to indicate that the relative demand for interactive and non-routine tasks falls in a Swedish plant that belongs to a Swedish multinational, when the Swedish multinational expands offshore to get better access to foreign markets. This result is somewhat surprising, but I propose two mechanisms that may help explain the result.

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Papers

PAPER 1

When Does Trade Liberalization Promote Economic Growth?

Damián Migueles Chazarreta

Abstract. This paper presents a dynamic general equilibrium model with trade between two structurally identical countries. There is endogenous skill acquisition by agents and innovation decisions by firms. I present two versions: one in which innovations consist of firms improving upon existing products (vertical innovation) and other in which firms develop new varieties (horizontal innovation). Contrary to results in the earlier literature, I find that trade liberalization can promote economic growth and increase the skilled-wage premium in both settings. The main result of the paper is that trade liberalization promotes growth and increases the relative wage of skilled workers when intellectual property rights protection is sufficiently weak.

JEL Classification: F10, F12, F13, O31, O41.

Keywords: Economic Growth, Intellectual Property Rights, Trade Costs.

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1. Introduction

Why is free trade preferred to protectionist policies? If one look for the answer in the widely used textbook *International Economics* by Paul Krugman and Maurice Obstfeld (2009), it is argued that the conventionally measured costs of deviating from free trade are large, there are additional benefits from free trade that add to the costs of protectionist policies when there are economies of scale in production, and any attempt to pursue sophisticated deviations from free trade is likely to be subverted by the political process. While these arguments are important, no reference is made to the role free trade plays in promoting technological change and economic growth.

Profits are partly a reward for research and developement (R&D) aimed at improving products or production processes. Lower trade costs increase profits from exporting and consequently overall profits. Trade liberalization can promote technological change by increasing the incentives for firms to conduct R&D and earn larger profits. But although this idea is intellectually appealing, it was not until the early 1990's that economists had endogenous growth models (EGMs) that could explain investments in R&D and technological change as the result of decisions of profit maximizing firms. Pioneering examples are Romer (1990), Segerstrom, Anant and Dinopoulos (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992). A common key feature of these models is that the perfect competition assumption is relaxed, letting firms earn monopoly profits that compensate them for the R&D investment they made in the past. The models of Romer (1990), Grossman and Helpman (1991) and Aghion and Howitt (1992) were closed economy models; but there were, however, interesting trade-policy implications: the long-run rate of economic growth is an increasing function of factor endowments, which has subsequently become known as the "scale effect" property. So, going from autarky to free trade in these types of models increases the size of the market, and therefore, the incentives for conducting R&D. The scale effect property is common to all these "first generation" EGMs and although first generation EGMs could explain the mechanism by which trade promoted growth, it was at odds with the empirical evidence, as pointed out by Jones (1995a). He presented evidence that there has been no upward trends in the economic growth rates of the US, France, Germany or Japan since 1950 in spite of substantial increases in population size and R&D employment.

Second generation EGMs were developed in response to the Jones critique. Examples are Jones (1995b), Kortum (1997), Segerstrom (1998), Young (1998) and Howitt (1999). By making different assumptions about the R&D technology, they got rid of this effect. Jones (1995b) modifies the R&D technology in Romer (1990) by assuming that existing knowledge does not contribute as much to the creation of new knowledge, that is, by assuming weaker knowledge spillovers in R&D activities. Kortum (1997) and Segerstrom (1998) modify the R&D technology in Grossman and Helpman (1991) so that innovating becomes progressively more difficult over time. These authors, in their striving to meet the Jones critique, focused on the steady-state (or balanced growth path) properties of closed economy models, leaving outside considerations of trade and its implications for growth.

Within the aforementioned literature there are two papers that emphasized the relation between trade and growth; one is Baldwin and Forslid (2000) and the other is Dinopoulos and Segerstrom (1999). Baldwin and Forslid, although strictly a first generation model due to its scale effect property, unifies existing results under an intuitive Tobin's q approach. They analyze the different channels through which trade promotes growth and show that trade liberalization can stimulate growth via a procompetitive effect in the R&D sector and/or the financial sector. Dinopoulos and Segerstrom (1999) propose a Schumpeterian second generation EGM with two factors: skilled and unskilled labor. Their main purpose is to explain the increasing skilled-wage premium observed since the 1950s (and that accelerated in the 1980s), as a consequence of more liberalized trade[1]. Lower trade costs encourage entrepreneurs to do skilled-labor intensive R&D that let their products penetrate world markets. Wage inequality is then a consequence of an increase in the relative demand for skilled workers when trade costs fall. One interesting feature of the model is that the increased level of R&D that follows trade liberalization leads to a temporary increase of the rate of technological change. That there is a strong and significant correlation between openness and growth has recently been well documented (see Wacziarg and Welch, 2008), so I see this as an advantage of the model. Baldwin and Forslid's paper, on the other hand, had a radically different result: trade liberalization (in the form of a reduction in the iceberg trade cost) has no impact on the rate of technical change. Neither the differences between the financial market specifications nor the market structures of the two papers are important for this result. What distinguishes one model fundamentally from the other is that Baldwin and Forslid assume that innovation takes the form of new varieties entering the market (horizontal innovation) while Dinopoulos and Segerstrom assume that innovation is vertical and takes the form of firms improving upon the quality of existing products (a vertical innovation "quality-ladder" model). I find that result to be puzzling because there is neither a formal nor an intuitive explanation for such an important difference, just based on the type of innovation.

[1] Epifani and Gancia (2007) present evidence indicating a positive correlation between openness and wage inequality. They also show that inequality persists long after trade is liberalized.

The new-new trade literature, pioneered by Melitz (2003), has shifted away the attention of trade economists from the trade and growth linkages for some time. In the new-new trade literature, firms are heterogenous and face fixed sunk costs for exporting in addition to variable trade costs, which means that only sufficiently productive firms export. Almost all new-new trade models have no steady-state productivity growth and are, therefore,unable to explain productivity growth as a consequence of trade liberalization. Baldwin and Robert-Nicoud (2008) were among the first to construct a new-new trade EGM. They use the increasing variety approach and show that for some R&D technologies, trade liberalization has a negative effect on productivity growth. In a recent paper Gustafsson and Segerstrom (2008) use a similar model and innovation technology but get rid of the strong scale effect of Baldwin and Robert-Nicoud. They show that whether trade liberalization reduces productivity growth (as Baldwin and Robert-Nicoud found) or not depends on the strength of R&D spillovers[2]. Migueles (2009) and Haruyama and Zhao (2009) on the other hand, using the quality-ladder approach show that trade liberalization always promotes productivity growth within a new-new EGM. Absent scale effects, these papers seem to provide robustness to this dichotomous puzzling result: Trade liberalization has no (or ambiguous) effects on growth when innovation is horizontal (new varieties), but promotes economic growth when innovation is vertical (better qualities). But has the new-new trade literature given us some understanding about the channels that are pro-growth and anti-growth in the vertical and horizontal innovation models? Haruyama and Zhao suggest that (in the vertical innovation case):

> "*trade liberalization unambiguously reallocates resources to R&D, accelerating the rate of technical progress. In the case of a lower transport cost, for example, the reason can be understood by identifying two channels that work to bring about this pro-growth result. First, a lower transport cost, which expands exporting industries, increases the expected sunk costs of developing a profitable product which includes costs for exporting. Resources are diverted from R&D through this sunk cost channel, discouraging R&D. Second, trade liberalization allows monopoly firms to raise the price-cost margin in the foreign market. Profits increase through this monopoly markup channel, boosting R&D incentives. In equilibrium, the monopoly markup channel always dominates the sunk cost channel, giving rise to our key result.*"

[2] Productivity growth increase due to trade liberalizaton when intertemporal knowledge spillovers in R&D are sufficiently weak. The results are reversed when intertemporal knowledge spillovers in R&D are sufficiently strong.

Whereas in the horizontal innovation case:

> "*the monopoly markup channel disappears in equilibrium due to the CES production function used to model variety expansion. Through the remaining sunk cost channel, trade liberalization encourages or discourages technical progress, depending upon the structure of knowledge assumed. The same reason applies for the result of Gustafsson and Segerstrom (2008) that the share of workers devoted to R&D is unaffected by trade liberalization.(...) In the variety-based models of Baldwin and Robert-Nicoud (2008), Gustafsson and Segerstrom (2007) and Unel (2006), aggregate profits are independent of the transport cost in equilibrium, because of the CES production functions assumed. (...) Instead, in our model of quality improvement, the production function is of a Cobb-Douglas type.*"

In this paper, I show that the presence of sunk costs, the CES production function, the structure of knowledge assumed and, most importantly, whether innovations are vertical or horizontal are not relevant for explaining and solving the puzzle presented here. I show that the underlying assumptions about intellectual property rights (IPRs) implicit in the widely used versions of the horizontal and vertical innovation EGMs are what determine whether trade liberalization promotes growth or not.

The typical vertical innovation model assumes that only the patent of the good with the latest quality improvement is protected, which means that anyone can produce the second best quality; that is, IPRs protection is weak in the sense that anyone can produce something similar to the highest quality at the same marginal cost as the leader. On the other hand, in horizontal innovation models where there are no quality differences (only different products), the underlying assumption is that there is strong IPRs protection: a new product is protected in the sense that its production is only permitted by other firms if they use an extremely inefficient production technology. The implicit IPRs assumptions embedded in these models are quite extreme and imply equally extreme price setting mechanisms for innovating firms: Leaders always charge limit prices in the vertical innovation model given the potential competition from other firms and leaders always charge monopoly prices in the horizontal innovation model since the marginal cost of potential competitors is so high that it does not change their monopolistic pricing strategy. Contrary to previous beliefs, I show that the *pricing strategy* is the transmission mechanism that connects trade liberalization with productivity growth. Whether firms charge monopoly or limit prices will affect their ability to pass on trade cost reductions to consumers (the mark-up channel). The pricing strategy will also determine the impact trade liberalization has on the competition among firms (the competition channel). These two effects interact when trade is liberalized and if the net impact of these effects on profits is positive, trade has a positive effect on productivity growth encouraging innovative work that accelerates technological change; while if the net effect on profits is zero, trade liberalization has no effects on productivity growth.

By relaxing the extreme assumptions on IPRs used in the trade and growth literature, I extend and generalize the models of Dinopoulos and Segerstrom (1999) and Baldwin and Forslid (2000). But more importantly, I show that all results obtained within the increasing variety framework can be obtained within the increasing quality framework and vice versa, providing a solution to the puzzle presented here.

The rest of the paper is organized as follows: in section 2, I present an EGM with vertical innovation similar to Dinopoulos and Segerstrom. I obtain all their results but show that these no longer hold once the implicit *weak* IPRs assumption is relaxed. In section 3, I slightly modify the model of section 2 by making it an EGM with horizontal innovation similar to Baldwin and Forslid. There I show that once the *strong* IPRs assumption is relaxed, all the main results in Dinopoulos and Segerstrom reemerge. Section 4 concludes.

2. A Model with Vertical Innovation

2.1. Overview. In this section, I present a dynamic two-country trade model. The two countries (Home and Foreign) are structurally identical and are connected by international trade. All trade between the two countries is subject to positive trade costs. I study the steady-state equilibrium implications of a reduction in these trade costs, with a particular interest in determining when trade liberalization promotes economic growth. The engine of economic growth in the model is vertical innovation: firms do innovative R&D with the goal of learning how to produce higher quality products.

The model has a quality ladders structure as in Segerstrom, Anant and Dinopoulos (1990) and Grossman and Helpman (1991). There is a continuum of industries indexed by $\omega \in [0, 1]$ where firms produce final consumption goods. In each industry ω, firms are distinguished by the quality of the products they produce. Higher values of the index j denote higher quality products and j is restricted to taking on integer values. At time $t = 0$, the state-of-the-art quality product in each industry is $j = 0$, that is, some firm in each industry knows how to produce a $j = 0$ quality product and no firm knows how to produce any higher quality product. To learn how to produce higher quality products, firms in each industry engage in innovative R&D. In general, when the state-of-the-art quality product in an industry is j, the next firm that innovates learns how to produce a $j+1$ quality product.

2.2. Households. There is a continuum of households in each country indexed by ability $\theta \in [0, 1]$. All members of household θ have the same ability level equal to θ, and all households have the same number of members at each point in time. Each household is modeled as a dynastic family whose size grows over time at an exogenously given rate $n > 0$. Each individual member of a household lives forever. Letting N_0 denote the number of members of each household at time $t = 0$, the population size in each country at time t is $N_t = N_0 e^{nt}$.

Household-optimization considerations determine the allocation of income across final goods, the evolution of consumption expenditure over time, and the decision whether to become skilled or enter the labor force as unskilled workers. In making these decisions, each family takes prices of final products, wages, and the interest rate as given.

Each individual knows her own ability level θ, as do all the firms that might potentially hire her. An individual can enter the labor force as unskilled and earn the wage w_L from then on. Alternatively, an individual with ability θ can enter the labor force after spending an exogenously given period of time T in "training" to become skilled. A skilled worker with ability θ earns a wage θw_H from then on and does not earn any income during her period of training or apprenticeship. Thus skilled workers with higher ability levels earn higher wages. I assume for simplicity that the training process does not require any real resources (other than the time of the trainee), and therefore, the opportunity cost of becoming a skilled worker equals the discounted value of forgone unskilled wage income. I also assume that income is evenly shared within each family (between employed and trainees) so that, at each point in time, consumption expenditure is the same for each member of a household.

Each household with ability θ maximizes the discounted utility function

$$U_\theta \equiv \int_0^\infty e^{-(\rho-n)t} \ln u_{\theta t}\, dt, \tag{2.1}$$

where $\rho > 0$ is the subjective discount rate and $u_{\theta t}$ is the static utility function of the representative household member. $\rho > n$ will be assumed to guarantee that the integral in (2.1) converges. The static utility function is given by

$$u_{\theta t} \equiv \left\{ \int_0^1 \left[\sum_j \lambda^j d_{\theta t}(j, \omega) \right]^\alpha d\omega \right\}^{1/\alpha}. \tag{2.2}$$

This is a quality-augmented CES utility function. The term $d_{\theta t}(j, \omega)$ denotes the consumer's quantity demanded of a good with j improvements (innovations) in its quality in industry $\omega \in [0, 1]$ at time t. The parameter $\lambda > 1$ captures the size of each quality improvement and λ^j denotes the total quality of a good after j innovations. Since λ^j is increasing in j, (2.2) captures in a simple way the idea that consumers prefer higher quality products. The parameter α determines the elasticity of substitution between products $\sigma \equiv \frac{1}{1-\alpha}$. I assume that $\alpha \in (0, 1)$, which implies that products in different industries are gross substitutes and $\sigma > 1$.

In their earlier model, Dinopoulos and Segerstrom (1999) assume same utility functions (2.1) and (2.2) but restrict attention to the limiting case $\sigma = 1$. They find that trade liberalization always promotes economic growth (when R&D is the skilled labor intensive activity relative to production of final goods). In this paper, I will show that this conclusion is not robust and no longer holds when $\sigma > 1$. Instead, I find that trade liberalization sometimes promotes economic growth and sometimes does not promote economic growth. Extending the framework in Dinoupoulos and Segerstrom (1999) to allow for $\sigma > 1$ is one of the main contributions of this paper.

Each household maximizes its discounted utility function (2.1) subject to the standard static and intertemporal budget constraints. This dynamic optimization problem can be solved in four steps.

The first step is to solve the within-industry static optimization problem

$$\max_{d_\theta(\cdot)} \sum_j \lambda^j d_{\theta t}(j, \omega) \qquad \text{subject to the constraint} \qquad c_{\theta t}(\omega) = \sum_j p_t(j, \omega) d_{\theta t}(j, \omega),$$

where $c_{\theta t}(\omega)$ is consumer expenditure in industry ω at time t and $p_t(j, \omega)$ is the price of the quality j product in industry ω at time t. This yields that each household allocates its expenditure within each industry by only buying the product with the lowest quality-adjusted price $\frac{p_t(j,\omega)}{\lambda^j}$.[3] If two products have the same quality-adjusted price and consumers are indifferent concerning which product to purchase, then I restrict attention to equilibria where consumers only buy the more advanced product (the product with higher quality or lower production cost).

The second step is to solve the across-industry static optimization problem

$$\max_{d_{\theta t}(\cdot)} \int_0^1 \left[\lambda^{j(\omega,t)} d_{\theta t}(\omega)\right]^\alpha d\omega \qquad \text{subject to} \qquad c_{\theta t} = \int_0^1 p_t(\omega) d_{\theta t}(\omega)\, d\omega,$$

[3] The easiest way to see this is to solve the simple consumer optimization problem $\max_{d_1,d_2} d_1 + \lambda d_2$ subject to $p_1 d_1 + p_2 d_2 = c$, $d_1 \geq 0$ and $d_2 \geq 0$. The solution is to only buy good 1 if $p_1 < \frac{p_2}{\lambda}$ and only buy good 2 if $p_1 > \frac{p_2}{\lambda}$.

where $j(\omega, t)$ is the quality index of the product purchased in industry ω at time t, $p_t(\omega)$ is the price of this product, and $d_{\theta t}(\omega)$ is the corresponding quantity demanded. Solving this static optimization problem using standard optimal control techniques (see the Appendix) yields the individual consumer demand function

$$d_{\theta t}(\omega) = \frac{q_t(\omega) p_t(\omega)^{-\sigma} c_{\theta t}}{P_t^{1-\sigma}} \tag{2.3}$$

for the product purchased in industry ω at time t, where $q_t(\omega) \equiv \lambda^{(\sigma-1)j(\omega,t)}$ is an alternative measure of product quality and P_t is a quality-adjusted price index given by

$$P_t \equiv \left[\int_0^1 q_t(\omega) p_t(\omega)^{1-\sigma} \, d\omega \right]^{1/(1-\sigma)}. \tag{2.4}$$

The quantity demanded for each of the remaining products in each industry is zero.

The third step is to maximize the discounted utility function (2.1) subject to the standard intertemporal budget constraint

$$W_\theta + Z_\theta = \int_0^\infty N_0 e^{nt} c_{\theta t} e^{-R(t)} \, dt,$$

where W_θ is the household's discounted wage income, Z_θ is the value of the household's financial assets, and $R(t) \equiv \int_0^t r_s \, ds$ is the market discount factor. Taking into account that the market interest rate r_t satisfies $r_t = \dot{R}(t)$ at each point in time t, the solution to this dynamic optimization problem is the standard intertemporal optimization condition

$$\frac{\dot{c}_{\theta t}}{c_{\theta t}} = r_t - \rho. \tag{2.5}$$

The differential equation (2.5) states that individual consumer expenditure grows over time if and only if the market interest rate exceeds the subjective discount rate. When the market interest rate is relatively high, consumers want to save more now and spend more later, resulting on positive growth in individual consumer expenditure over time.

The fourth and final step is to solve for the training/employment decisions that maximize each household's discounted utility. Since each household's discounted utility is increasing in consumer expenditure and there is no disutility associated with training or working, each household maximizes its discounted utility by maximizing its discounted wage income. This is equivalent to maximizing each household member's discounted wage income, which depends on whether the individual member earns the unskilled wage or becomes a skilled worker and then earns the skilled wage. It is optimal for an individual with ability θ born at time t to train and become a skilled worker if

$$\int_t^\infty e^{-[R(s)-R(t)]} w_{Ls}\, ds < \int_{t+T}^\infty e^{-[R(s)-R(t)]} \theta w_{Hs}\, ds. \tag{2.6}$$

The left-hand side (LHS) of inequality (2.6) equals the discounted wage income of an individual from being employed as an unskilled worker and earning the wage w_L from time t on. The RHS of (2.6) is the lifetime income of a skilled worker, who earns zero income during her training period and θw_H from time $t+T$ on.

I focus on the model's steady-state equilibrium properties where the wage terms w_L, w_H and consumer expenditure c_θ are all constants over time. Then (2.5) implies that $r_t = \rho$ for all t.

Condition (2.6) can be used to determine endogenously the steady-state supply of unskilled labor. Because the RHS of (2.6) is increasing in θ, whereas the LHS is independent of θ, there exists a level of ability denoted by θ_0 such that (2.6) holds as an equality. All individuals with ability lower than θ_0 choose to remain unskilled, and all individuals with ability greater than θ_0 undergo training and then enter the labor force as skilled workers. Setting (2.6) to hold as an equality yields $\int_t^\infty e^{-\rho(s-t)} w_L\, ds = \int_{t+T}^\infty e^{-\rho(s-t)} \theta_0 w_H\, ds$, which simplifies to $\frac{w_L}{\rho} = \frac{e^{-\rho T}\theta_0 w_H}{\rho}$. Solving for the steady-state value of θ_0 then yields

$$\theta_0 = \frac{w_L}{w_H} e^{\rho T}. \tag{2.7}$$

Equation (2.7) implies that the wage of a skilled worker θw_H must always be higher than the wage of any unskilled worker w_L. An increase in the duration of training T or in the relative wage of unskilled labor w_L/w_H increases the fraction of the population that chooses to remain unskilled θ_0.

The supply of unskilled labor in each country at time t, L_t, equals the number of individuals in the population that choose to remain unskilled:

$$L_t = \theta_0 N_t. \tag{2.8}$$

The derivation of the steady-state supply of skilled labor at time t is slightly more complicated. A fraction $(1-\theta_0)$ of each country's population train and become skilled workers, and therefore, $(1-\theta_0)N_t$ individuals either work as skilled workers or are training to become skilled workers in each country at time t. In this sub-population, the skilled workers are the older individuals, namely, those individuals that were born before $t-T$:

$$\int_{-\infty}^{t-T} n(1-\theta_0) N_s\, ds = n(1-\theta_0)\int_{-\infty}^{t-T} N_0 e^{ns}\, ds = (1-\theta_0)e^{-nT} N_t.$$

The average skill level of workers $\theta \in [\theta_0, 1]$ that have finished training equals $\frac{\theta_0+1}{2}$, and therefore, the supply of skilled labor at time t, measured in efficiency units of human capital, is given by $H_t = \frac{(\theta_0+1)(1-\theta_0)}{2} e^{-nT} N_t$ or more simply

$$H_t = \frac{[1-(\theta_0)^2]}{2} e^{-nT} N_t. \tag{2.9}$$

It is obvious from equations (2.7), (2.8) and (2.9) that a decline in the relative wage of unskilled workers decreases θ_0 and L_t, and increases H_t, resulting in a rise of skilled labor abundance H_t/L_t in each country. In steady-state equilibrium, each country's factor supplies grow at the same rate as the population because θ_0 is constant over time: $\frac{\dot{H}_t}{H_t} = \frac{\dot{L}_t}{L_t} = \frac{\dot{N}_t}{N_t} = n$.

2.3. Firms. In each industry, firms employ workers in two activities: producing final consumption goods and doing innovative R&D to develop higher quality goods. I assume that only skilled workers can engage in R&D activities and only unskilled workers are employed in production activities. This strong assumption is not needed for the results that I derive but it considerably simplifies the derivation. In the more general case where both factors are employed in both activities, I obtain the same results provided that R&D is the skilled labor-intensive activity relative to the production of final goods.

In each industry, I refer to the firm that has most recently innovated as the industry leader. The identity of the industry leader changes over time as new firms succeed in developing higher quality products. When a firm is an industry leader, it has a simple production technology: one unit of unskilled labor produces one unit of output and production is characterized by constant returns to scale. There are also trade costs separating the two countries that take the "iceberg" form: $\tau > 1$ units of a good must be produced and exported in order to have one unit arriving at its destination. Taking into account the trade costs, the marginal cost of an industry leader serving the domestic market is w_L and the marginal cost of an industry leader serving the foreign market is τw_L.

When a firm innovates and becomes an industry leader, it receives patent protection in both countries. But this patent protection is characterized by finite patent breadth. Firms cannot copy the new technology developed by the industry leader but they can produce using a substitute technology provided that the substitute technology is not too close to the industry leader's patented technology. Let β be the measure of patent breadth in each industry. I assume that firms in both countries can produce the same quality product as the industry leader but they have to use an inferior production technology to avoid violating the industry leader's patent. For these non-leader firms,

$\beta > 1$ units of unskilled labor produce one unit of output and consequently, each non-leader firm has constant marginal cost of production equal to βw_L.

In their earlier model, Dinopoulos and Segerstrom (1999) assume that when a firm innovates and becomes an industry leader, the production technology of the previous industry leader ceases to receive patent protection and is immediately copied by firms in both countries. In terms of the model in this section, this assumption is equivalent to assuming that $\beta = \lambda$, that is, patent breadth coincides with innovation size. In this paper, I allow β to take on a range of values and just assume that $1 < \beta \leq \lambda$. Extending the framework in Dinopoulos and Segerstrom (1999) to explicitly model patent breadth is the second main contribution of this paper.

In each industry, firms compete in prices and maximize their profits from producing at each point in time t. I will now solve for the profit-maximizing behavior of firms in product markets. Variables with an asterisk (*) refer to the Foreign country and variables without an asterisk refer to the Home country. To simplify expressions, I set $w_L = 1$ and suppress time subscripts when solving for firm profits, bearing in mind that the profits earned by firms change over time.

Consider first the case of a Home industry leader that exports its product to the Foreign market (the analysis of a Foreign industry leader exporting to Home consumers is identical because of structural symmetry between the two countries). The Home industry leader has marginal cost τw_L when serving the Foreign market and competes against a competitive fringe of Foreign firms that sell the same quality product but have higher marginal cost βw_L. Let q_ℓ^* denote the output that the Home leader sells to Foreign consumers, let p_ℓ^* denote the price that Foreign consumers pay for the state-of-the-art quality product, and let p_f^* denote the price that competitive fringe firms charge Foreign consumers. With the competitive fringe of Foreign firms charging the competitive price $p_f^* = \beta w_L$, the profit flow earned by the Home leader from selling to Foreign consumers is

$$\pi_\ell^* = \begin{cases} p_\ell^* q_\ell^* - \tau q_\ell^* & \text{if } \beta \geq p_\ell^* \\ 0 & \text{if } \beta < p_\ell^* \end{cases}$$

If the price charged by the Home leader is too high ($\beta < p_\ell^*$), then all Foreign consumers buy from Foreign firms. The Home leader has to charge a sufficiently low price to attract Foreign consumers ($\beta \geq p_\ell^*$) and I assume that in the borderline case ($\beta = p_\ell^*$) where consumers are indifferent, they only buy the more advanced (lower production cost) product that the Home leader sells. Focusing on the $\beta \geq p_\ell^*$ case and using (2.3), the profit flow earned by the Home leader becomes

$$\pi_\ell^* = \frac{(p_\ell^* - \tau) q_t(\omega) (p_\ell^*)^{-\sigma} c^* N_t^*}{P_t^{1-\sigma}} \tag{2.10}$$

where c^* is average consumer expenditure and N_t^* is the number of consumers in the Foreign country. Maximizing this expression with respect to p_ℓ^* yields the pure monopoly price τ/α. Thus the profit-maximizing price of the Home leader in the export market is

$$p_\ell^* = \begin{cases} \tau/\alpha & \text{if } \beta \geq \tau/\alpha \\ \beta & \text{if } \beta < \tau/\alpha. \end{cases} \tag{2.11}$$

The Home leader charges the monopoly price τ/α if patent protection is sufficiently broad ($\beta \geq \tau/\alpha$) and charges the limit price β if patent protection is sufficiently narrow ($\beta < \tau/\alpha$).

Consider next the case of a Home industry leader that sells its product domestically to Home consumers (the analysis of a Foreign industry leader selling to Foreign consumers is identical because of structural symmetry between the two countries). The Home industry leader has marginal cost w_L when serving the Home market and competes against a competitive fringe of Home firms that sell the same quality product but have higher marginal cost βw_L. Let q_ℓ denote the output that the Home leader sells to Home consumers, let p_ℓ denote the price that Home consumers pay for the state-of-the-art quality product, and let p_f denote the price that competitive fringe firms charge Home consumers. With the competitive fringe of Home firms charging the competitive price $p_f = \beta w_L$, the profit flow earned by the Home leader from selling to Home consumers is

$$\pi_\ell = \begin{cases} p_\ell q_\ell - q_\ell & \text{if } \beta \geq p_\ell \\ 0 & \text{if } \beta < p_\ell \end{cases}$$

If the price charged by the Home leader is too high ($\beta < p_\ell$), then all Home consumers buy from Home competitive fringe firms. The Home leader has to charge a sufficiently low price to attract Home consumers ($\beta \geq p_\ell$) and I assume that in the borderline case ($\beta = p_\ell$) where consumers are indifferent, they only buy the more advanced (lower production cost) product that the Home leader sells. Focusing on the $\beta \geq p_\ell$ case and using (2.3), the profit flow earned by the Home leader becomes

$$\pi_\ell = \frac{(p_\ell - 1)q_t(\omega)(p_\ell)^{-\sigma} c N_t}{P_t^{1-\sigma}} \tag{2.12}$$

where c is average consumer expenditure in the Home country. Maximizing this expression with respect to p_ℓ yields the pure monopoly price $1/\alpha$. Thus the profit-maximizing price of the Home leader in the domestic market is

$$p_\ell = \begin{cases} 1/\alpha & \text{if } \beta \geq 1/\alpha \\ \beta & \text{if } \beta < 1/\alpha. \end{cases} \tag{2.13}$$

The Home leader charges the monopoly price $1/\alpha$ if patent protection is sufficiently broad ($\beta \geq 1/\alpha$) and charges the limit price β if patent protection is sufficiently narrow ($\beta < 1/\alpha$).

Given (2.11) and (2.13), there are three cases that need to be considered when solving for industry leader profits: the $\beta \geq \tau/\alpha \geq 1/\alpha$ case where industry leaders charge the monopoly price $p_\ell = 1/\alpha$ in the domestic market and the monopoly price $p_\ell^* = \tau/\alpha$ in the export market, the $\tau/\alpha > \beta \geq 1/\alpha$ case where industry leaders charge the monopoly price $p_\ell = 1/\alpha$ in the domestic market and the limit price $p_\ell^* = \beta$ in the export market, and the $\tau/\alpha \geq 1/\alpha > \beta$ case where industry leaders charge the limit price $p_\ell = \beta$ in the domestic market and the limit price $p_\ell^* = \beta$ in the export market. I will now consider each case in turn.

In the $\beta \geq \tau/\alpha \geq 1/\alpha$ case where industry leaders charge monopoly prices in both markets, the profit flows that industry leaders earn from both domestic and export sales are

$$\pi \equiv \pi_\ell + \pi_\ell^* = \left(\frac{1}{\alpha} - 1\right) \frac{q_t(\omega)(1/\alpha)^{-\sigma} c N_t}{P_t^{1-\sigma}} + \left(\frac{\tau}{\alpha} - \tau\right) \frac{q_t(\omega)(\tau/\alpha)^{-\sigma} c^* N_t^*}{P_t^{1-\sigma}}.$$

Since industry leaders charge the domestic price $1/\alpha$ in 50% of industries and the export price τ/α in the other 50% of industries, the price index satisfies $P_t^{1-\sigma} = \int_0^1 q_t(\omega) p_t(\omega)^{1-\sigma}\, d\omega = \frac{1}{2} Q_t \left\{ (1/\alpha)^{1-\sigma} + (\tau/\alpha)^{1-\sigma} \right\}$ where $Q_t \equiv \int_0^1 q_t(\omega)\, d\omega$ is the average quality of products. Taking into account that $cN_t = c^* N_t^*$, the profit flows earned by industry leaders can be written more simply as

$$\pi \equiv \pi_\ell + \pi_\ell^* = \gamma_M \frac{q_t(\omega)}{Q_t} c N_t \tag{2.14}$$

where $\gamma_M \equiv 2(1-\alpha)$ (the "M" subindex is a mnemonic for "monopoly pricing") is a constant term and does not depend on τ. Industry leader profits π are an increasing function of the relative quality of the firm's product $q_t(\omega)/Q_t$ and also increase over time due to growth in the number of consumers in each country N_t.

In the $\tau/\alpha > \beta \geq 1/\alpha$ case where industry leaders charge the monopoly price $1/\alpha$ in the domestic market and the limit price β in the export market, the profit flows that industry leaders earn from both domestic and export sales are

$$\pi \equiv \pi_\ell + \pi_\ell^* = \left(\frac{1}{\alpha} - 1\right) \frac{q_t(\omega)(1/\alpha)^{-\sigma} c N_t}{P_t^{1-\sigma}} + (\beta - \tau) \frac{q_t(\omega)\beta^{-\sigma} c N_t}{P_t^{1-\sigma}}$$

and the price index satisfies $P_t^{1-\sigma} = \int_0^1 q_t(\omega) p_t(\omega)^{1-\sigma}\, d\omega = \frac{1}{2} Q_t \left\{ (1/\alpha)^{1-\sigma} + \beta^{1-\sigma} \right\}$. The profit flows that industry leaders earn can be written more simply as

$$\pi \equiv \pi_\ell + \pi_\ell^* = \gamma_{ML} \frac{q_t(\omega)}{Q_t} c N_t \tag{2.15}$$

where $\gamma_{ML} \equiv 2\left[(\frac{1}{\alpha}-1)(\frac{1}{\alpha})^{-\sigma}+(\beta-\tau)\beta^{-\sigma}\right]/\left[(\frac{1}{\alpha})^{1-\sigma}+\beta^{1-\sigma}\right]$ (the "ML" subindex is a mnemonic for "monopoly and limit pricing"). Although γ_{ML} is a complicated expression, all that will be important in subsequent analysis is that it is a decreasing function of τ.

Finally, in the $\tau/\alpha \geq 1/\alpha > \beta$ case where industry leaders charge the limit price β in both domestic and export markets, the profit flows that industry leaders earn from both domestic and export sales are

$$\pi \equiv \pi_\ell + \pi_\ell^* = (\beta-1)\frac{q_t(\omega)\beta^{-\sigma}cN_t}{P_t^{1-\sigma}} + (\beta-\tau)\frac{q_t(\omega)\beta^{-\sigma}cN_t}{P_t^{1-\sigma}}$$

and the price index satisfies $P_t^{1-\sigma} = \int_0^1 q_t(\omega)p_t(\omega)^{1-\sigma}\,d\omega = Q_t\beta^{1-\sigma}$. The profit flows that industry leaders earn can be written more simply as

(2.16)
$$\pi \equiv \pi_\ell + \pi_\ell^* = \gamma_L \frac{q_t(\omega)}{Q_t} cN_t$$

where $\gamma_L \equiv 2 - \frac{1+\tau}{\beta}$ (the "L" subindex is a mnemonic for "limit pricing") is another decreasing function of τ.

The product market equilibrium has two interesting features. First, trade liberalization has no direct effect on the overall profits $\pi_\ell + \pi_\ell^*$ earned by industry leaders when these firms receive broad patent protection $\beta \geq \tau/\alpha$ and practice monopoly pricing. A reduction in τ contributes to increasing export profits π_ℓ^* but domestic profits π_ℓ decrease due to the more competitive environment and these two effect cancel each other out, leaving $\pi_\ell + \pi_\ell^*$ unaffected. Second, trade liberalization directly increases the overall profits $\pi_\ell + \pi_\ell^*$ earned by industry leaders when these firms receive narrow patent protection $\beta < \tau/\alpha$ and practice limit pricing in the export market.

2.4. Innovation and Economic Growth. There are sequential and stochastic R&D races in each industry $\omega \in [0,1]$. These races result in the discovery of higher-quality products. All firms participating in a R&D race use the same R&D technology and there is free entry into each race.

A firm i that hires $h_i(\omega,t)$ skilled workers to engage in R&D in industry ω at time t is successful in discovering the next higher quality product with instantaneous probability

(2.17)
$$I_i(\omega,t) = \frac{Q_t^\phi h_i(\omega,t)}{q_t(\omega)},$$

where $\phi > 0$ is a knowledge-spillover parameter. By instantaneous probability (or Poisson arrival rate), I mean that $I_i(\omega,t)\,dt$ is the probability that the firm will innovate by time $t+dt$ conditional on not having innovated by time t, where dt is an infinitesimal increment of time. This R&D technology introduced in Li (2003) implies that innovating because more difficult as product quality $q_t(\omega)$ increases. It also highlights the positive knowledge-spillover effects across industries which are found to be significant in empirical studies since increases in average product quality Q_t make innovating less difficult.[4]

The returns to R&D investment are independently distributed across firms, across industries, and over time. Thus the industry-wide instantaneous probability of success in industry ω at time t is $I(\omega,t) = \sum_i I_i(\omega,t)$. I solve the model for a symmetric steady-state equilibrium where the innovation rates are constant over time and do not vary across industries, that is, $I(\omega,t) = I$ for all ω and t. Given symmetry across countries, half of I is driven by Home R&D and half of I is driven by Foreign R&D.

From (2.17), $q_t(\omega)/Q_t^{\phi}$ is a measure of R&D difficulty in industry ω at time t. Integrating over industries, $\int_0^1 q_t(\omega)/Q_t^{\phi}\, d\omega = Q_t^{1-\phi}$ is a measure of aggregate R&D difficulty at time t. Thus, it is natural to define relative R&D difficulty (or R&D difficulty relative to the size of the economy) as

$$x \equiv \frac{Q_t^{1-\phi}}{N_t}. \tag{2.18}$$

I claim that in any steady-state equilibrium where the innovation rate I is constant over time, relative R&D difficulty x must also be constant over time. To see this, first note from (2.17) that $I = Q_t^{\phi}\sum_i h_i(\omega,t)/q_t(\omega)$ or $Iq_t(\omega)/Q_t^{\phi} = \sum_i h_i(\omega,t)$. Then integrating over industries yields $IQ_t^{1-\phi} = H_t$ since all skilled workers are employed in R&D activities. Since $Q_t^{1-\phi}/H_t$ is constant over time and $\dot{H}_t/H_t = \dot{N}_t/N_t$, it follows that $Q_t^{1-\phi}/N_t$ is also constant over time.

To determine the steady-state innovation rate I, I first solve for the growth rate of the average quality of products. From $Q_t \equiv \int_0^1 q_t(\omega)\, d\omega = \int_0^1 \lambda^{(\sigma-1)j(\omega,t)}\, d\omega$, it follows that $\dot{Q}_t = \int_0^1 \{\lambda^{(\sigma-1)[j(\omega,t)+1]} - \lambda^{(\sigma-1)j(\omega,t)}\} I\, d\omega = (\lambda^{\sigma-1}-1)IQ_t$. Thus the growth rate of average product quality $\dot{Q}_t/Q_t = (\lambda^{\sigma-1}-1)I$ is an increasing function of the innovation rate I and the innovation size parameter λ. Since relative R&D difficulty $x \equiv Q_t^{1-\phi}/N_t$ can only be constant over time if $(1-\phi)\dot{Q}_t/Q_t = \dot{N}_t/N_t$ or $(1-\phi)(\lambda^{\sigma-1}-1)I = n$, it immediately follows that the steady-state innovation rate is

$$I = \frac{n}{(1-\phi)(\lambda^{\sigma-1}-1)}. \tag{2.19}$$

[4] The presence of the $q_t(\omega)$ term in (2.17) is the reason why the model does not have the scale effect property. In the first-generation endogenous growth model by Grossman and Helpman (1991), this term is absent and consequently the long-run economic growth rate is an increasing function of population size in their model.

Given the steady-state innovation rate, I can solve for the corresponding steady-state growth rate of consumer utility. By substituting for consumer demand (2.3) into the static utility function (2.2), I obtain

$$u_{\theta t} \equiv \left\{ \int_0^1 \left[\lambda^{j(\omega,t)} d_{\theta t}(\omega) \right]^{\alpha} d\omega \right\}^{1/\alpha} = \left\{ \int_0^1 \left[\lambda^{j(\omega,t)} \frac{q_t(\omega) p_t(\omega)^{-\sigma} c_\theta}{P_t^{1-\sigma}} \right]^{\alpha} d\omega \right\}^{1/\alpha}.$$

Since consumers see the price p_ℓ in 50% of industries and the price p_ℓ^* in the other 50% of industries, the price index satisfies $P_t^{1-\sigma} = \int_0^1 q_t(\omega) p_t(\omega)^{1-\sigma} d\omega = \frac{1}{2} Q_t \left\{ (p_\ell)^{1-\sigma} + (p_\ell^*)^{1-\sigma} \right\}$. Also $\lambda^{j(\omega,t)\alpha} q_t(\omega)^\alpha = \lambda^{j(\omega,t)\alpha} \lambda^{(\sigma-1)j(\omega,t)\alpha} = \lambda^{\sigma j(\omega,t)\alpha} = q_t(\omega)$ since $\sigma\alpha = \sigma - 1$. Consequently, consumer utility simplifies to

$$u_{\theta t} = \frac{c_\theta}{P_t^{1-\sigma}} \left\{ \int_0^1 q_t(\omega) p_t(\omega)^{1-\sigma} d\omega \right\}^{1/\alpha} = \frac{c_\theta}{P_t}.$$

Since $\dot{u}_{\theta t}/u_{\theta t} = -\dot{P}_t/P_t$ and $(1-\sigma)\dot{P}_t/P_t = \dot{Q}_t/Q_t = (\lambda^{\sigma-1}-1)I$, it immediately follows that the steady-state growth rate of consumer utility is

$$g_u \equiv \frac{\dot{u}_{\theta t}}{u_{\theta t}} = \frac{\lambda^{\sigma-1} - 1}{\sigma - 1} I = \frac{n}{(\sigma - 1)(1 - \phi)} \tag{2.20}$$

The utility growth rate g_u is increasing in the population growth rate n, is increasing in the strength of knowledge-spillovers ϕ and is decreasing in the elasticity of substitution between products σ. Since this utility growth rate is also the real wage growth rate, it is the proper measure of economic growth in the model.

Equations (2.19) and (2.20) have two important implications. First, they imply that public policy changes like trade liberalization (a decrease in τ) have no effect on the steady-state rate of innovation I and hence the steady-state rate of economic growth g_u. In this model, growth is "semi-endogenous." I view this as a virtue of the model because both total factor productivity and per capita GDP growth rates have been remarkably stable over time in spite of many public policy changes that one might think would be growth-promoting. For example, plotting data on per capita GDP (in logs) for the US from 1880 to 1987, Jones (1995a) shows that a simple linear trend fits the data extremely well. This data leads me to be skeptical about models where public policy changes have large long-run growth effects. Second, they imply that the level of per capita income in the long run is an increasing function of the size of the economy (because positive population growth is associated with positive economic growth). Jones (2005) has a lengthy discussion of this "weak scale effect" property and cites Alcala and Ciccone (2004) as providing the best empirical support. Controlling for both trade and institutional quality, Alcala and Ciccone find that a

10 percent increase in the size of the workforce in the long run is associated with 2.5 percent higher GDP per worker.

2.5. R&D Incentives. There is a global stock market that channels consumer savings to firms that engage in R&D. Because there is a continuum of industries with simultaneous R&D races, consumers can diversify completely the industry-specific risk and earn the risk-free interest rate $r_t = \rho$. Each firm engaged in R&D issues a security that pays the flow of industry leader profits if the firm wins the R&D race and zero if it does not win the race. Let $v_{\omega t}$ denote the expected discounted profits of the industry leader in industry ω at time t and let $\pi_{\omega t}$ now denote the global profit flow earned by the industry leader in industry ω at time t. Because each industry leader is targeted by R&D firms in both countries that try to discover the next higher quality product, the shareholder suffers a loss $v_{\omega t}$ if further innovation occurs.[5] This event occurs with probability $I dt$ during the time interval dt, whereas the event of no innovation occurs with probability $1 - I dt$. Over the time interval dt, the shareholder of a stock issued by a successful R&D firm receives a dividend $\pi_{\omega t} dt$ and the value of the firm appreciates by $\dot{v}_{\omega t} dt$. The stock market values the firm so that its expected rate of return just equals the riskless rate of return ρ:

$$\frac{\dot{v}_{\omega t}}{v_{\omega t}}(1 - I dt)dt - \frac{v_{\omega t} - 0}{v_{\omega t}} I dt + \frac{\pi_{\omega t}}{v_{\omega t}} dt = \rho\, dt.$$

Dividing both sides by dt and then taking the limit as $dt \to 0$ yields $\frac{\dot{v}_{\omega t}}{v_{\omega t}} - I + \frac{\pi_{\omega t}}{v_{\omega t}} = \rho$, which can be rewritten as

$$v_{\omega t} = \frac{\pi_{\omega t}}{\rho + I - \frac{\dot{v}_{\omega t}}{v_{\omega t}}}. \tag{2.21}$$

The global profit flow $\pi_{\omega t}$ earned by an industry leader is appropriately discounted using the market interest rate ρ and the instantaneous probability I of being driven out of business by further innovation (the creative-destruction effect). Also taken into account in (2.21) are the capital gains $\dot{v}_{\omega t}/v_{\omega t}$ that accrue to the firm as time passes.

Consider a firm i that engages in R&D in industry ω at time t. This firm chooses its R&D intensity I_i to maximize its expected discounted profits, that is, it solves the problem

$$\max_{I_i}\ v_{\omega t} I_i\, dt - w_H I_i q_t(\omega) Q_t^{-\phi}\, dt,$$

[5] Because industry leaders have less to gain from innovating than other firms, all R&D is done by non-leader firms in equilibrium. For a model where industry leaders have cost advantages and thus engage in R&D, see Segerstrom (2007).

where I have substituted for $h_i(\omega, t)$ using (2.17). Free entry into each R&D race drives these expected discounted profits down to zero and implies that

$$v_{\omega t} = \frac{w_H q_t(\omega)}{Q_t^{\phi}}. \tag{2.22}$$

The reward for innovating $v_{\omega t}$ is higher in industries where product quality $q_t(\omega)$ is higher since industry leaders earn higher profit flows when they have a higher quality product to sell. During an R&D race, the quality of the industry leader's product does not change, so $\dot{v}_{\omega t}/v_{\omega t} = -\phi \dot{Q}_t/Q_t = -\phi(\lambda^{\sigma-1} - 1)I$. The stock market value of each industry leader falls over time because knowledge spillovers contribute to decreasing both the cost and the benefit of innovating.

Using (2.21) and (2.22) as well as the profit expressions (2.14), (2.15) and (2.16), the free entry condition becomes

$$v_{\omega t} = \frac{\gamma_i \frac{q_t(\omega)}{Q_t} c N_t}{\rho + I + \phi(\lambda^{\sigma-1} - 1)I} = \frac{w_H q_t(\omega)}{Q_t^{\phi}} \qquad i \in \{M, ML, L\}$$

Dividing both sides by $q_t(\omega)N_t/Q_t$, I obtain the steady-state R&D condition

$$\frac{\gamma_i c}{\rho + I + \phi(\lambda^{\sigma-1} - 1)I} = w_H x \qquad i \in \{M, ML, L\}. \tag{2.23}$$

The LHS is the market size-adjusted benefit from innovating and the RHS is the market size-adjusted cost of innovating. In steady-state calculations, I need to adjust for market size because market size changes over time due to increases in the number of consumers N_t, improvements in own product quality $q_t(\omega)$ and improvements in the quality of other products Q_t. The market size-adjusted benefit from innovating is higher when the average consumer buys more ($c \uparrow$), future profits are less heavily discounted ($\rho \downarrow$) and industry leaders are less threatened by further innovation ($I \downarrow$). Trade liberalization also contributes to increasing the market size-adjusted benefit from innovating when industry leaders receive narrow patent protection and practice limit-pricing in the export market [$\tau \downarrow \Rightarrow \gamma_i \uparrow$ if $i \in \{ML, L\}$]. The market size-adjusted cost of innovating is higher when skilled workers earn a higher wage ($w_H \uparrow$) and innovating is relatively more difficult ($x \uparrow$).

2.6. Labor Markets. Labor markets are perfectly competitive, workers are perfectly mobile across industries and wages adjust instantaneously to equate labor demand and labor supply. Because both countries are structurally identical, I concentrate on the derivation of equilibrium for the Home country.

The supply of unskilled labor is given by $L(t) = \theta_0 N(t)$. The demand for unskilled labor comes from production by industry leaders since only industry leaders produce in equilibrium and unskilled labor is only employed in production activities. The assumption of structurally identical countries implies that 50% of the world's industry leaders are Home firms and 50% are Foreign firms. In industries with a Home industry leader (exporting industries), total output produced equals $q_\ell + \tau q_\ell^*$. The Home industry leader produces output q_ℓ for the Home market and taking into account trade costs, the Home quality leader needs to produce output τq_ℓ^* at Home in order to sell output q_ℓ^* in the Foreign market. In industries with a Foreign industry leader, total Home output is zero. Therefore, full employment of unskilled labor requires that

$$L(t) = \theta_0 N(t) = \frac{1}{2}\int_0^1 (q_\ell + \tau q_\ell^*) d\omega = \frac{1}{2}\int_0^1 \left(\frac{q_t(\omega)(p_\ell)^{-\sigma} c N_t}{P_t^{1-\sigma}} + \tau \frac{q_t(\omega)(p_\ell^*)^{-\sigma} c N_t}{P_t^{1-\sigma}} \right) d\omega.$$

Dividing both sides by $N(t)$ and taking into account that $P_t^{1-\sigma} = \frac{1}{2} Q_t \left\{ (p_\ell)^{1-\sigma} + (p_\ell^*)^{1-\sigma} \right\}$ yields $\theta_0 = \eta c$ where $\eta \equiv [(p_\ell)^{-\sigma} + \tau (p_\ell^*)^{-\sigma}]/[(p_\ell)^{1-\sigma} + (p_\ell^*)^{1-\sigma}]$. This equation can be rewritten in a more convenient form by substituting for the unknown c. Equation (2.7) implies that $w_H = e^{\rho T}/\theta_0$ and then equation (2.23) implies that $c = [\rho + I + \phi(\lambda^{\sigma-1} - 1)I] e^{\rho T} x / [\gamma_i \theta_0]$. Substituting for c yields the steady-state unskilled labor condition in (x, θ_0) space:

$$(2.24) \qquad (\theta_0)^2 = [\rho + I + \phi(\lambda^{\sigma-1} - 1)I] e^{\rho T} \left[\frac{\eta}{\gamma_i} \right] x \qquad i \in \{M, ML, L\}.$$

Equation (2.24) is a full employment condition for unskilled labor that takes into account the implications of profit-maximizing R&D behavior by firms. An increase in θ_0 increases the LHS, so x must increase on the RHS to restore equality in (2.24), given that I is pinned down by (2.19). It follows that the steady-state unskilled labor condition is upward-sloping in (x, θ_0) space.

The intuition behind the upward slope is as follows: Suppose that there is a decline in the skilled wage w_H, making it less attractive for workers to acquire skills and increasing the supply of unskilled labor ($\theta_0 \uparrow$). In steady-state equilibrium, any increase in the supply of unskilled labor must be matched by an increase in the demand for unskilled labor. But firms only want to hire more unskilled workers in production (the only activity where they are employed by assumption) if there is stronger consumer demand for their products. Stronger consumer demand increases the benefit from innovating and the initial fall in the skilled wage w_H decreases the cost of innovating. Profit-maximizing firms respond to these incentives by devoting more resources to R&D, resulting in a long-run increase in relative R&D difficulty x. Thus, to satisfy both labor-market clearing and R&D optimization conditions, any increase in the supply of unskilled labor ($\theta_0 \uparrow$) must be matched by an increase in consumer expenditure, which stimulates R&D investment and serves to raise the long-run level of relative R&D difficulty x.

The supply of skilled labor in the Home country is given by $H(t) = [1-(\theta_0)^2]e^{-nT}N(t)/2$. The demand for skilled labor comes from R&D since skilled labor is only employed in R&D activities. From (2.17), $I = Q_t^{\phi}h(\omega,t)/q_t(\omega)$ where $h(\omega,t)$ is the global skilled labor employed in industry ω at time t. Rearranging yields $h(\omega,t) = Iq_t(\omega)/Q_t^{\phi}$ and integrating over all industries yields $\int_0^1[Iq_t(\omega)/Q_t^{\phi}]d\omega = IQ_t^{1-\phi}$. Since 50% of global R&D is done by Home firms, full employment of skilled labor requires that $H(t) = [1-(\theta_0)^2]e^{-nT}N(t)/2 = IQ_t^{1-\phi}/2$. Dividing both sides by $N(t)$ and simplifying using $x \equiv Q_t^{1-\phi}/N_t$ yields the steady-state skilled labor condition in (x, θ_0) space:

$$1-(\theta_0)^2 = [Ie^{nT}]x. \tag{2.25}$$

Equation (2.25) is a full employment condition for skilled labor that takes into account the skill acquisition process. An increase in θ_0 decreases the LHS, so x must decrease on the RHS to restore equality in (2.25), given that I is pinned down by (2.19). It follows that the steady-state skilled labor condition is downward-sloping in (x, θ_0) space.

The intuition behind the downward slope is straightforward: Suppose that there is a decline in the skilled wage w_H, making it less attractive for workers to acquire skills and decreasing the supply of skilled labor ($\theta_0 \uparrow$). In steady-state equilibrium, any decrease in the supply of skilled labor must be matched by a decrease in the demand for skilled labor. Since the steady-state innovation rate $I = n/[(1-\phi)(\lambda^{\sigma-1}-1)]$ is constant and given by parameter values, firms only hire less skilled workers in R&D (the only activity where they are employed by assumption) if R&D becomes relatively less difficult ($x \downarrow$). Thus, to satisfy market clearing for skilled labor, any decrease in the supply of skilled labor ($\theta_0 \uparrow$) must be matched by a decrease in the demand for skilled labor in R&D and this only occurs if R&D becomes relatively less difficult ($x \downarrow$).

2.7. Steady-State Equilibrium Properties. Solving the model for a symmetric steady-state equilibrium reduces to solving the system of 2 equations [(2.24), (2.25)] in 2 unknowns [x, θ_0]. These equations are illustrated in Figure 1 and are labeled "Unskilled" and "Skilled", respectively. Given that the steady-state unskilled labor condition is globally upward-sloping and goes through the origin, the steady-state skilled labor condition is globally downward-sloping with strictly positive intercepts, these two curves must have a unique intersection. Thus, the steady-state equilibrium values of x and θ_0 are uniquely determined and are given by point A in Figure 1. Since (2.7) then uniquely determines w_H, I have established that the model has a unique symmetric steady-state equilibrium.

To determine the steady-state equilibrium effects of a permanent reduction in trade costs τ, there are three cases that need to be considered: $\beta \geq \tau/\alpha \geq 1/\alpha$, $\tau/\alpha > \beta \geq 1/\alpha$ and $\tau/\alpha \geq 1/\alpha > \beta$.

In the $\beta \geq \tau/\alpha \geq 1/\alpha$ case where industry leaders charge the monopoly price $p_\ell = 1/\alpha$ in the domestic market and the monopoly price $p^*_\ell = \tau/\alpha$ in the export market, the critical term η/γ_i in (2.24) equals

$$\frac{\eta}{\gamma_M} = \left[\frac{(1/\alpha)^{-\sigma} + \tau(\tau/\alpha)^{-\sigma}}{(1/\alpha)^{1-\sigma} + (\tau/\alpha)^{1-\sigma}}\right] \frac{1}{2(1-\alpha)} = \frac{\alpha}{2(1-\alpha)}$$

and does not depend on τ. Consequently, decreasing τ on the margin has no effect on either the unskilled labor condition (2.24) or the skilled labor condition (2.25). Neither labor condition shifts and as illustrated in Figure 1, the steady-state equilibrium continues to be given by point A. A decrease in τ leads to no change in θ_0, x or w_H.

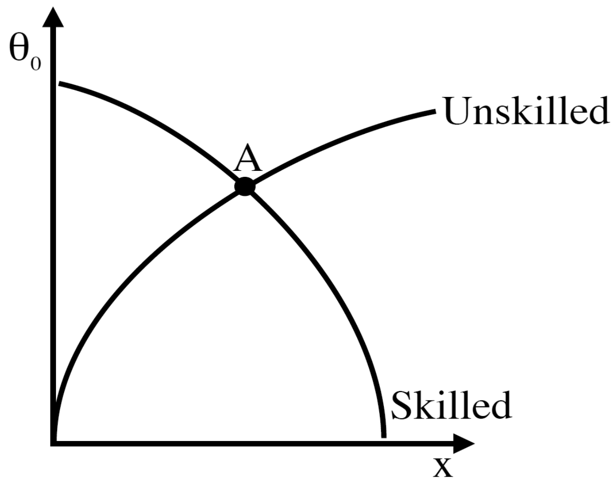

Figure 1: The effects of trade liberalization when $\beta > \tau/\alpha$

In the $\tau/\alpha > \beta \geq 1/\alpha$ case where industry leaders charge the monopoly price $p_\ell = 1/\alpha$ in the domestic market and the limit price $p^*_\ell = \beta$ in the export market, the critical term η/γ_i in (2.24) equals

$$\frac{\eta}{\gamma_{ML}} = \left[\frac{(1/\alpha)^{-\sigma} + \tau(\beta)^{-\sigma}}{(1/\alpha)^{1-\sigma} + \beta^{1-\sigma}}\right] \frac{(1/\alpha)^{1-\sigma} + \beta^{1-\sigma}}{2(\frac{1}{\alpha}-1)(\frac{1}{\alpha})^{-\sigma} + 2(\beta-\tau)\beta^{-\sigma}} = \frac{(1/\alpha)^{-\sigma} + \tau(\beta)^{-\sigma}}{2(\frac{1}{\alpha}-1)(\frac{1}{\alpha})^{-\sigma} + 2(\beta-\tau)\beta^{-\sigma}}$$

and is an increasing function of τ. A decrease in τ has no effect on the skilled labor condition (2.25) but causes the RHS of the unskilled labor condition (2.24) to decrease for any given value of x. Thus, the unskilled labor condition shifts down as illustrated in Figure 2 and there is a new intersection of the two curves given by point B. A decrease in τ leads to a permanent decrease in θ_0 and a permanent increase in x. From (2.7), the permanent decrease in θ_0 is associated with a permanent increase in w_H.

In the $\tau/\alpha \geq 1/\alpha > \beta$ case where industry leaders charge the limit price $p_\ell = \beta$ in the domestic market and the limit price $p_\ell^* = \beta$ in the export market, the critical term η/γ_i in (2.24) equals

$$\frac{\eta}{\gamma_L} = \left[\frac{\beta^{-\sigma} + \tau(\beta)^{-\sigma}}{\beta^{1-\sigma} + \beta^{1-\sigma}}\right] \frac{1}{2 - \frac{1+\tau}{\beta}} = \left[\frac{4\beta}{1+\tau} - 2\right]^{-1}$$

and is an increasing function of τ. As in the second case, a decrease in τ has no effect on the skilled labor condition (2.25) but causes the RHS of the unskilled labor condition (2.24) to decrease for any given value of x. Thus, the unskilled labor condition shifts down as illustrated in Figure 2 and there is a new intersection of the two curves given by point B. A decrease in τ leads to a permanent decrease in θ_0, a permanent increase in x and from (2.7), a permanent increase in w_H.

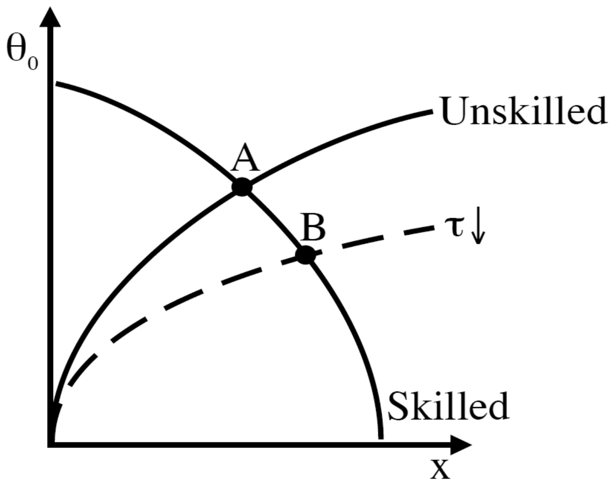

Figure 2: The effects of trade liberalization when $\tau/\alpha \geq \beta$

To see the implications of a permanent increase in x, I take logs and differentiate the definition $x \equiv \frac{Q_t^{1-\phi}}{N_t}$ to obtain

$$\frac{\dot{x}_t}{x_t} = (1-\phi)\frac{\dot{Q}_t}{Q_t} - \frac{\dot{N}_t}{N_t} = (1-\phi)(\lambda^{\sigma-1} - 1)I - n. \tag{2.26}$$

In any steady-state equilibrium, $I = n/[(1-\phi)(\lambda^{\sigma-1}-1)]$ implies that x is constant over time ($\dot{x}_t = 0$). Thus, for x to permanently increase, the global innovation rate in each industry I must temporarily increase above its steady-state level $I = n/[(1-\phi)(\lambda^{\sigma-1}-1)]$. I have established

THEOREM 1. *If firms receive narrow patent protection ($\tau/\alpha > \beta$), then trade liberalization that takes the form of a permanent reduction in trade costs ($\tau \downarrow$) leads to a permanent increase in the relative wage of skilled labor ($w_H/w_L \uparrow$), a permanent increase in the fraction of the population that chooses to acquire skills ($\theta_0 \downarrow$), and a temporary increase in the global innovation rate in each industry ($I \uparrow$).*

On the other hand, if firms receive broad patent protection ($\beta \geq \tau/\alpha$), then trade liberalization that takes the form of a permanent reduction in trade costs ($\tau \downarrow$) leads to no change in the relative wage of skilled labor (w_H/w_L constant), no change in the fraction of the population that chooses to acquire skills (θ_0 constant), and no change in the global innovation rate in each industry (I constant).

The properties of this model when firms receive narrow patent protection are quite intuitive. When trade costs fall, firms earn higher profits from exporting their products and consequently their overall profits increase [$\tau \downarrow \Longrightarrow \pi \uparrow$ from equations (2.15) and (2.16)]. Because these profits are a reward for developing better products, it follows that when trade costs fall, firms have a stronger incentive to develop better products [$\tau \downarrow \Longrightarrow v_{\omega t} \uparrow$ from equation (2.22)]. The demand by firms for skilled workers capable of doing R&D increases, bidding up the relative wage of skilled labor [$w_H/w_L \uparrow$]. When workers see that the reward for becoming skilled has gone up, more workers choose to undergo the training needed to acquire skills [$w_H/w_L \uparrow \Longrightarrow \theta_0 \downarrow$ from equation (2.7)], global R&D employment increases [$\theta_0 \downarrow \Longrightarrow [1-(\theta_0)^2]e^{-nT}N_t \uparrow$ from equation (2.9)] and the global economy experiences a faster rate of technological change [$x \uparrow \Longrightarrow I \uparrow$ from equation (2.26)]. The model highlights a potentially very important benefit of trade liberalization, namely, that it promotes technological change.

Theorem 1 also establishes that trade liberalization does not always promote technological change. Whether or not trade liberalization promotes technological change depends on the strength of intellectual property protection. When firms receive broad patent protection (intellectual property protection is strong), then trade liberalization does not promote technological change, does not lead to any skill-upgrading and has no effect on relative wages. The key is that trade liberalization does not contribute to increasing overall firm profits when firms receive broad patent protection [$\tau \downarrow \Longrightarrow \pi$ constant, from equation (2.14)]. Firms earn higher profits from exporting π_ℓ^* but profits from domestic sales π_ℓ decrease due to the more competitive environment and these two effect cancel each other out, leaving $\pi_\ell + \pi_\ell^*$ unaffected. Since trade liberalization does not change the overall profits that firms earn from innovating, firms do not increase their R&D activities, the wage of skilled workers is not bid up and the fraction of workers that acquire skills does not increase.

3. A Model with Horizontal Innovation

3.1. Overview. In this section, I present a modified version of the model of section 2. Here, the engine of economic growth is horizontal innovation: firms do innovative R&D with the goal of learning how to produce new product varieties. There is a continuum of industries and each industry is characterized by a differentiated variety that was developed through costly R&D by an "innovating" or "leader" firm. Within each industry, there is a competitive fringe of "followers" that can either produce the same good the leader produces but at a higher marginal cost or can engage in costly R&D in order to develop a new variety/industry. So, given the presence of followers, once a new variety is discovered, the leader decides its pricing strategy depending on the competition he faces. He might either charge a limit price if the marginal cost of followers is low or a monopoly price if the marginal cost of followers is high.

In previous models with horizontal innovation (Baldwin and Forslid, 2000; Baldwin and Robert-Nicoud, 2008; Gustafsson and Segerstrom, 2010), the underlying assumption is that there is strong IPRs protection since no reference is made to competition from a competitive fringe. Implicitly (although not discussed in any of these papers), this is equivalent to assuming that the marginal cost for followers is extremely high. In consequence, leaders will be able to charge monopoly prices without losing any consumers. In this section I extend the framework in Baldwin and Forslid (among others) to allow for both strong and weak IPRs protection. This is the third main contribution of the paper.

The results are identical to those of section 2: trade liberalization promotes economic growth if IPRs protection is not too strong (patent breadth is not too broad). This is stated in Theorem 2 and proves that all results of the vertical innovation model can be obtained within the horizontal innovation model (and vice versa).

3.2. Households. Households in this section are as in section 2.2. The only difference is that while in that section I used a quality-augmented CES utility function in order to capture the number and size of quality improvements, here, quality is constant but the number of varieties increases, so I use a standard CES utility function instead.

The optimization problem of a family with ability $\theta \in (0, 1)$ is to maximize its discounted utility:

$$\max_{d_{\theta t}} U_\theta = \int_0^\infty e^{-(\rho-n)t} \ln u_{\theta t} dt \tag{3.1}$$

where ρ is the subjective discount rate and n is the population growth rate. Optimization is subject to the following constraints:

$$u_{\theta t} \equiv \left[\int_0^{m_t^c} d_{\theta t}(\omega)^\alpha d\omega\right]^{1/\alpha} \tag{3.2}$$

$$c_{\theta t} = \int_0^{m_t^c} p_t(\omega) d_{\theta t}(\omega) d\omega \tag{3.3}$$

$$W_\theta + Z_\theta = \int_0^\infty N_0 c_{\theta t} e^{nt} e^{-R_t} dt \tag{3.4}$$

Equation (3.2) is the static utility function of each household member where $d_{\theta t}(\omega)$ is the demand for good ω at time t by a member of a household with ability θ. The parameter α determines the elasticity of substitution between varieties $\sigma \equiv \frac{1}{1-\alpha}$. I assume that $\alpha \in (0,1)$, which implies that products in different industries are gross substitutes and $\sigma > 1$. m_t^c is the available number of varieties at time t consumed in an economy. Equation (3.3) indicates that the value of all goods consumed must be equal to per capita consumption expenditure $c_{\theta t}$. Equation (3.4) is an intertemporal budget constraint: W_θ is the family´s discounted wage income and Z_θ is the value of the family´s financial assets; the RHS equals the discounted value of the family´s consumption and $R_t \equiv \int_0^t r_s ds$ is the market discount factor with $\dot{R}_t = r_t$ denoting the interest rate at time t.

I solve the family´s dynamic optimization problem by first solving the static maximization problem at given time t:

$$\max_{d_{\theta t}} \left[\int_0^{m_t^c} d_{\theta t}(\omega)^\alpha d\omega\right]^{1/\alpha}$$

subject to (3.3). Solving this static optimization problem using standard optimal control techniques (see the Appendix) yields the individual consumer demand function

$$d_{\theta t}(\omega) = \frac{p_t(\omega)^{-\sigma} c_{\theta t}}{P_t^{1-\sigma}} \tag{3.5}$$

where $P_t \equiv \left[\int_0^{m_t^c} p_t(\omega)^{1-\sigma} d\omega\right]^{\frac{1}{1-\sigma}}$ is the aggregate price index.

The intertemporal maximization problem is then

$$\max_{c_{\theta t}} U_{\theta} = \int_0^{\infty} e^{-(\rho-n)t} \ln u_{\theta t} dt$$

subject to

$$W_{\theta} + Z_{\theta} = \int_0^{\infty} N_0 c_{\theta t} e^{nt} e^{-R(t)} dt.$$

The solution to this dynamic optimization problem satisfies the standard intertemporal optimization condition

$$\frac{\dot{c}_{\theta t}}{c_{\theta t}} = r_t - \rho, \tag{3.6}$$

which indicates that per capita consumption expenditure grows if the subjective discount rate ρ is lower than the market interest rate. I will focus on the steady-state properties of the model where per capita consumption is constant, implying that $r_t = \rho$.

The final step is to solve for the training/employment decisions. These are the same as those presented in section 2.2 and indicate that it is optimal for an individual with ability θ born at time t to train and become a skilled worker if

$$\int_t^{\infty} e^{-[R(s)-R(t)]} w_L(s)\, ds < \int_{t+T}^{\infty} e^{-[R(s)-R(t)]} \theta w_H(s)\, ds. \tag{3.7}$$

Similarly, the threshold value θ_0 is

$$\theta_0 = e^{\rho T} (w_L / w_H) \tag{3.8}$$

and the share θ_0 of the population N_t that will remain unskilled is

$$L_t = \theta_0 N_t. \tag{3.9}$$

The supply of skilled labor at time t, measured in efficiency units of human capital is

$$H_t = \frac{(1-\theta_0^2)}{2} \left[e^{-nT} N_t \right]. \tag{3.10}$$

In the steady-state equilibrium, factor supplies grow at the same rate as the population because θ_0 is constant over time:

$$\frac{\dot{H}_t}{H_t} = \frac{\dot{L}_t}{L_t} = \frac{\dot{N}_t}{N_t} = n.$$

3.3. Firms. In each industry, firms employ workers in two activities: producing final consumption goods and doing innovative R&D to develop new products. I assume that only skilled workers can engage in R&D activities and only unskilled workers are employed in production activities. This strong assumption is not needed for the results that I derive but it considerably simplifies the derivation. In the more general case where both factors are employed in both activities, I obtain the same results provided that R&D is the skilled-labor-intensive activity relative to the production of final goods.

In each industry, I refer to the firm that has developed a blueprint as the industry leader. When a firm is an industry leader, it has a simple production technology: one unit of unskilled labor produces one unit of output and production is characterized by constant returns to scale. There are also trade costs separating the two countries that take the "iceberg" form: $\tau > 1$ units of a good must be produced and exported in order to have one unit arriving at its destination. Taking into account the trade costs, the marginal cost of an industry leader serving the domestic market is w_L and the marginal cost of an industry leader serving the foreign market is τw_L.

When a firm innovates and becomes an industry leader, it receives patent protection in both countries. But this patent protection is characterized by finite patent breadth: follower firms cannot use the new technology developed by the industry leader to produce its product. I assume that follower firms in both countries can produce the same *variety* as the industry leader but they have to use an *inferior* production technology to avoid violating the industry leader's patent rights. This inferior technology implies that followers will have to produce at a higher marginal cost than the leader. Following the notation of section 2, follower firms require $\beta > 1$ units of unskilled labor to produce one unit of output and consequently, each follower firm has constant marginal cost of production equal to βw_L. They are therefore willing to sell at the price βw_L. The parameter β can be interpreted as a measure of patent breadth in each industry.

In their model, Baldwin and Forslid (2000) do not discuss IPRs issues, but what they do is equivalent to assuming that when a firm develops a new product, rival follower firms can produce exactly the same product but at a very high (or infinite) marginal cost. That is, patent breadth is infinite ($\beta = +\infty$) or sufficiently broad. In this paper, I allow β to take on a range of values, extending the framework in Baldwin and Forslid (2000) to explicitly model patent breadth.

Firms compete in prices and maximize their profits at each point in time. I will now solve for the profit-maximizing behavior of firms in product markets. Variables with an asterisk (*) refer to the Foreign country and variables without an asterisk refer to the Home country. To simplify expressions, I set $w_L = 1$ and suppress time subscripts when solving for firm profits, bearing in mind that the profits earned by firms change over time.

Consider first the case of a Home industry leader that exports its product to the Foreign market (the analysis of a Foreign industry leader exporting to Home consumers is identical because of structural symmetry between the two countries). The Home industry leader has marginal cost τw_L when serving the Foreign market and competes against a competitive fringe of Foreign firms that can sell the same product but have higher marginal cost βw_L. Let $q_\ell^* = d^* N_t^*$ denote the output that the Home leader sells to Foreign consumers where d^* is average consumer demand. Let p_ℓ^* denote the price that Foreign consumers pay for a Home-produced variety, and let p_f^* denote the price that competitive fringe firms charge Foreign consumers.

Depending on how broad (or narrow) patent breadth is, I identify three pricing strategies for a leader: i) pure monopoly pricing, ii) pure limit pricing, and iii) part limit pricing.

3.3.1. *Pure Monopoly Pricing.* I first consider the case when innovative firms receive broad patent breadth: $\beta > \tau/\alpha$.

The Home industry leader's profits from exporting are $\pi_\ell^* = p_\ell^* q_\ell^* - \tau q_\ell^*$. The maximization problem of the exporting firm is therefore

$$\max_{p_\ell^*} \pi_l^* = p_\ell^* q_\ell^* - \tau q_\ell^*$$

subject to (3.5), which yields the monopoly price

$$p_\ell^* = \frac{\tau}{\alpha}. \tag{3.11}$$

By setting $\tau = 1$, I get the monopoly price the leader charges at Home:

$$p_\ell = \frac{1}{\alpha}. \tag{3.12}$$

Consumers in the Foreign market will pay τ times more per unit than Home consumers for Home produced goods. It follows that the price index satisfies

$$P_t^{1-\sigma} = \int_0^{m_t^H} p_\ell^{1-\sigma} d\omega + \int_0^{m_t^F} (\tau p_\ell)^{1-\sigma} d\omega$$

where m_t^H and m_t^F are the number of varieties produced in the Home and Foreign locations respectively. Given symmetry, both countries produce exactly the same amount of varieties ($m_t^H = m_t^F = m_t$), so

$$P_t^{1-\sigma} = m_t p_\ell^{1-\sigma} \left(1 + \tau^{1-\sigma}\right) \tag{3.13}$$

when firms firms receive broad patent breadth and practice monopoly pricing.

Given equations (3.11) and (3.12), the profit flow earned by a Home exporter becomes

$$\pi_\ell^* = \frac{(1-\alpha)\,\tau^{1-\sigma}}{m_t\left(1+\tau^{1-\sigma}\right)} c^* N_t^* \tag{3.14}$$

where c^* is the average consumer expenditure and N_t^* is the number of consumers in the Foreign country. In a similar way, I obtain the profit flow earned at Home by a leader

$$\pi_\ell = \frac{(1-\alpha)}{m_t\left(1+\tau^{1-\sigma}\right)} c N_t. \tag{3.15}$$

Total profit flow is therefore $\pi = \pi_\ell^* + \pi_\ell = \frac{(1-\alpha)\tau^{1-\sigma}}{m_t(1+\tau^{1-\sigma})} c^* N_t^* + \frac{(1-\alpha)}{m_t(1+\tau^{1-\sigma})} c N_t$. Symmetry implies that $c^* = c$ and that $N_t^* = N_t$. It follows that

$$\pi = \gamma_M \frac{cN_t}{m_t} \tag{3.16}$$

where $\gamma_M \equiv 1-\alpha$. What is important to notice from this result is that a decrease in the trade cost τ leaves profits unaffected. The reason behind this result is that if trade costs fall, the cost reductions are passed on to Foreign consumers, which increases demand while leaving the marginal revenue unaffected. This allows them to gain market shares in the Foreign market and hence increase profits. But due to symmetry, this increase in profits is completely canceled out by the effect more competition from Foreign firms has in the Home market. Foreign firms, as their Home counterparts, are now selling cheaper products in the Home market, taking market shares from Home firms.

3.3.2. *Pure limit pricing.* In the pure monopoly pricing case, I assumed that patent protection was broad because the marginal cost for producing an existing variety was very high: $\beta > \frac{\tau}{\alpha}$, implying that only leaders produce and charge monopoly prices. Now, I will assume that IPRs protection is weak and innovative firms receive narrow patent breadth. This implies that follower firms in both countries can produce the same product but at a marginal cost $\beta < 1/\alpha$.

When patent breadth is sufficiently broad ($\beta > \frac{\tau}{\alpha}$), the leader will be able to appropriate all monopoly rents derived by his innovation and the profit maximizing price is described by equations (3.11)-(3.12) since each follower's marginal cost is higher than either monopoly price. If patent breadth is narrow such that $\beta < 1/\alpha$, the pricing strategy of the leader is constrained: if he charges $p_\ell^* > \beta$ in the Foreign market and $p_\ell > \beta$ in the Home market, his sales in each of these markets will be zero given that followers charge β. Consumers buy the product with the lowest price, and in case of a tie, I will assume they choose the product of the firm that first entered the market. It follows that the leader will charge the limit price β and that followers get zero sales in equilibrium.

The profit function for a Home leader exporting to Foreign is then slightly different from (3.14). Since the price it gets abroad for every shipped unit is β and it costs τw_L to produce one unit that is being sold in the export market, the profit flow is $\pi_\ell^* = \beta q_\ell^* - \tau q_\ell^*$. Using equation (3.5) this can be rewritten as[6]

$$\pi_\ell^* = (\beta - \tau)\frac{c^* N_t^*}{2m_t\beta}. \tag{3.17}$$

The profit flow earned from selling in the Home market is

$$\pi_\ell = (\beta - 1)\frac{cN_t}{2m_t\beta}. \tag{3.18}$$

Total profits $\pi = \pi_\ell^* + \pi_\ell = \frac{cN_t}{2m_t\beta}(\beta - \tau + \beta - 1)$ can be written more simply as

$$\pi = \gamma_L \frac{cN_t}{m_t} \tag{3.19}$$

where $\gamma_L \equiv [2\beta - (\tau + 1)]/2\beta$. It follows that stronger IPRs protection (represented by a higher β) increases profits. Similarly, a decrease in the trade cost τ increases total profits as due to its impact on π_ℓ^* through γ_L. The reason is that if patent protection is narrow ($\beta < 1/\alpha$), the competitive fringe of firms restricts the ability a leader has to charge monopoly prices. In consequence, Home leaders practice limit pricing in both Foreign and Home markets. Limit pricing implies that prices are independent of trade costs. So if τ falls, their market shares remain unaffected. Lower trade costs, however, reduce costs for shipping to the export market, increasing the profits from exporting. Given that prices at Home are also unchanged (since Foreign´s exporters also charge limit prices), the market shares of Home firms are unaffected and overall profits increase in consequence.

3.3.3. *Part limit pricing.* The third possibility is that the patent breadth parameter β takes on an intermediate value:

$$\frac{\tau}{\alpha} > \beta > \frac{1}{\alpha}.$$

The pricing strategy of the leader is again constrained. The first part of the inequality means that patent breadth is too narrow for charging monopoly prices in the Foreign market, while the second part indicates that patent breadth is sufficiently broad for charging monopoly prices in the Home market. It follows that the leader will charge the limit price β in the Foreign market and the monopoly price $1/\alpha$ in the Home market.

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[6] Equation (3.5) implies that $\pi_\ell^* = (\beta - \tau)\frac{\beta^{-\sigma}}{P_t^{1-\sigma}}c^* N_t^*$. Given that $p_\ell^* = p_\ell = \beta$, the price index is $P_t^{1-\sigma} = \int_0^{m_t^F}\beta^{1-\sigma}d\omega + \int_0^{m_t^H}\beta^{1-\sigma}d\omega = \left(m_t^F + m_t^H\right)\beta^{1-\sigma} = 2m_t\beta^{1-\sigma}$ so $\pi_\ell^* = (\beta - \tau)\frac{\beta^{-\sigma}}{[2m_t\beta^{1-\sigma}]}c^* N_t^* = (\beta - \tau)\frac{c^* N_t^*}{[2m_t\beta]}$.

A Home leader exporting to Foreign charge β for every unit being sold in that market while it costs him τw_L to produce every shipped unit. The profits earned by an exporting Home producer are $\pi_\ell^* = \beta q_\ell^* - \tau q_\ell^*$. Using equation (3.5) , it can be rewritten as

$$\pi_\ell^* = \left(1 - \frac{\tau}{\beta}\right) \frac{\beta^{1-\sigma}}{P_t^{1-\sigma}} c^* N_t^*. \tag{3.20}$$

Similarly, the profit stream from selling in the Home market $\pi_\ell = \frac{1}{\alpha} q_\ell - q_\ell$ can be rewritten as

$$\pi_\ell = [1-\alpha] \frac{\left(\frac{1}{\alpha}\right)^{1-\sigma}}{P_t^{1-\sigma}} c N_t. \tag{3.21}$$

Given that the prices charged at Home and Foreign differ, the price index satisfies

$$\begin{aligned} P_t^{1-\sigma} &= \int_0^{m_t^F} \beta^{1-\sigma} d\omega + \int_0^{m_t^H} \left(\frac{1}{\alpha}\right)^{1-\sigma} d\omega \\ &= m_t \left[\beta^{1-\sigma} + \left(\frac{1}{\alpha}\right)^{1-\sigma}\right]. \end{aligned} \tag{3.22}$$

Total profits $\pi = \pi_\ell^* + \pi_\ell = \frac{cN_t}{P_t^{1-\sigma}} \left[\left(1 - \frac{\tau}{\beta}\right) \beta^{1-\sigma} + (1-\alpha) \left(\frac{1}{\alpha}\right)^{1-\sigma}\right]$ can therefore be expressed as

$$\pi = \gamma_{ML} \frac{cN_t}{m_t} \tag{3.23}$$

where $\gamma_{ML} \equiv \left[\left(1 - \frac{\tau}{\beta}\right) \beta^{1-\sigma} + (1-\alpha) \left(\frac{1}{\alpha}\right)^{1-\sigma}\right] / \left[\beta^{1-\sigma} + \left(\frac{1}{\alpha}\right)^{1-\sigma}\right]$. As in the pure limit pricing case, a decrease in the trade cost τ increases the profits of each producer. The reason is that when $\tau/\alpha > \beta > 1/\alpha$, the presence of a competitive fringe of firms restricts the leader's ability to charge the monopoly price in the Foreign market. In consequence, Home leaders practice limit pricing in the Foreign market but charge the monopoly price in the Home market (part limit pricing). If trade costs τ fall, profits increase in the Foreign market as in the limit pricing case. But Home firms charge monopoly prices in their Home market that are independent of τ and Foreign´s exporters charge limit prices that are also independent of τ. It follows that market shares and profits in the Home market are unchanged for Home firms if τ falls. The overall effect of trade liberalization on profits is therefore positive.

3.4. Innovation and Economic Growth. To innovate and develop a new product variety, a representative firm i must devote a/K^ϕ units of skilled labor at time t to innovative R&D, where a is exogenously given and measures R&D productivity, ϕ measures the strength of intertemporal knowledge spillovers and K is the available stock of knowledge. I will assume that this stock is proportional to the number of varieties in the world. More precisely, I choose units such that $K \equiv m_t^H + \kappa m_t^F$. Given symmetry, it follows that

$$\frac{a}{K^\phi} = \frac{a}{\left(m_t^H + \kappa m_t^F\right)^\phi} = \frac{a}{(1+\kappa)^\phi m_t^\phi}$$

where κ measures the international dimension of spillovers. $\kappa = 0$ corresponds to no international spillovers and $\kappa = 1$ corresponds to perfect international spillovers. I allow for all the inbetween possibilities. I assume that $\phi < 1$ to guarantee that the economic growth rate is finite[7]. If $\phi < 0$, labor becomes less productive as the stock of knowledge increases over time. Researchers experience a "fishing out" effect. If $\phi > 0$, labor becomes more productive as the stock of knowledge increases over time. Researchers experience a "standing on the shoulders" effect. This technology is a generalization of the closed-economy R&D technology in Jones (1995b).

The rate at which the representative firm i at Home discovers a new variety is

$$\dot{m}_{it} = \frac{h_{it}}{\frac{a}{(1+\kappa)^\phi m_t^\phi}} = \frac{(1+\kappa)^\phi m_t^\phi h_{it}}{a}$$

where $\dot{m}_{it}$ is the time derivative of m_{it} and h_{it} is the skilled labor used in R&D by firm i at time t. Summing over all firms at Home gives the aggregate number of new varieties $\Sigma_i \dot{m}_{it} = \dot{m}_t = (1+\kappa)^\phi m_t^\phi \Sigma_i h_{it}/a$ or

$$\dot{m}_t = \frac{(1+\kappa)^\phi m_t^\phi H_t}{a} \tag{3.24}$$

where H_t is the skilled labor used in innovative work given by equation (3.10).

The ratio $a/K^\phi = a/(1+\kappa)^\phi m_t^\phi$ can be understood as a measure of R&D difficulty. The relevant measure of market size for each firm N_t/m_t follows from analyzing the profit equations (3.16), (3.19) and (3.23). It is then natural to define relative R&D difficulty (or R&D difficulty relative to the size of the market) as

$$x_t \equiv \frac{a/K^\phi}{N_t/m_t} = \frac{a m_t^{1-\phi}}{N_t (1+\kappa)^\phi}. \tag{3.25}$$

I claim that in a steady-state equilibrium where the innovation rate is constant, relative R&D difficulty is constant as well. To see this, let $g \equiv \frac{\dot{m}_t}{m_t}$ denote the steady-state innovation rate. Then an alternative expression for $\frac{\dot{m}_t}{m_t}$ can readily be derived from equation (3.24) by dividing both sides by m_t:

$$g \equiv \frac{\dot{m}_t}{m_t} = \frac{(1+\kappa)^\phi (m_t)^{\phi-1} H_t}{a}.$$

[7] Grossman and Helpman (1991) assume that $\phi = 1$ and $n = 0$. Consequently, they find that larger economies grow faster (the strong scale effect property). This property is at odds with the evidence cited in Jones (1995).

Considering that in steady-state the growth rate of m_t must be constant, when I log-differentiate this expression, I get $0 = (\phi - 1) g + n$, so

$$g \equiv \frac{\dot{m}_t}{m_t} = \frac{n}{(1-\phi)}, \tag{3.26}$$

which is the steady-state innovation rate. It follows immediately that $\dot{x}_t/x_t = 0$, so relative R&D diffculty x_t is constant in steady-state and I will therefore omit the time subindex when referring to its steady-state value x.

3.5. R&D Incentives. There is a global stock market that channels consumer savings into firms that engage in R&D. For the owners of a leader firm, profits $\pi_t dt$ are earned during the time interval dt. The capital gain $\dot{v}_t dt$ is also realized where v_t is the expected discounted profits of an innovating firm and can be thought as the reward for innovating. As there is no risk for the owners of a firm once they undertake R&D investments (all R&D efforts end up in new blueprints), the stock market values the firm so that its expected rate of return just equals the riskless rate of return $r = \rho$. The relevant no-arbitrage condition is therefore given by $\rho v_t dt = \pi_t dt + \dot{v}_t dt$. Dividing both sides by dt and then taking the limit as dt converges to 0 yields $\rho = \frac{\pi_t}{v_t} + \frac{\dot{v}_t}{v_t}$, which can be rewritten as $v_t = \pi_t / (\rho - \dot{v}_t/v_t)$.

Given that there is free entry into variety innovation, in equilibrium the reward for innovating must be equal to the cost for innovating, that is, the cost of developing a new variety $\frac{w_H a}{(1+\kappa)^\phi m_t^\phi}$. It follows that

$$v_t = \frac{\pi_t}{\rho - \dot{v}_t/v_t} = \frac{w_H a}{(1+\kappa)^\phi m_t^\phi} \tag{3.27}$$

which can be interpreted as a "free-entry condition".

Depending on how narrow or broad patent breadth is, condition (3.27) can be combined with equations (3.16), (3.19) or (3.23) to get

$$\frac{\gamma_i \frac{cN_t}{m_t}}{\rho + \phi \frac{n}{(1-\phi)}} = \frac{w_H a}{(1+\kappa)^\phi m_t^\phi} \qquad i \in \{M, ML, L\}.$$

Dividing both sides by N_t/m_t, I get

$$\frac{\gamma_i c}{\rho + \phi \frac{n}{(1-\phi)}} = w_H x \qquad i \in \{M, ML, L\}. \tag{3.28}$$

Equation (3.28) is a market size-adjusted R&D condition similar to equation (2.23) that simply means that the market size-adjusted reward for innovating is equal to the market size-adjusted cost of innovating. I need to adjust for market size because market size changes over time as the number of consumers N_t and varieties m_t increase. The market size-adjusted benefit from innovating is higher when the average consumer buys more

($c \uparrow$), future profits are less heavily discounted ($\rho \downarrow$) and new varieties are introduced at a lower pace ($\phi \downarrow$). Trade liberalization also contributes to increase the market size-adjusted benefit from innovating (the LHS) when leaders receive narrow patent protection and practice limit-pricing or part limit pricing [$\tau \downarrow \Rightarrow \gamma_i \uparrow$ if $i \in \{ML, L\}$]. The market size-adjusted cost of innovating (the RHS) is higher when skilled workers earn a higher wage ($w_H \uparrow$) and innovating is relatively more difficult ($x \uparrow$).

3.6. Labor Markets. Labor markets are competitive, workers are perfectly mobile across industries and wages adjust instantaneously to equate labor demand and labor supply. Because both countries are structurally identical, I concentrate on the derivation of the equilibrium for the Home country.

The supply of unskilled labor is given by equation (3.9), $L_t = \theta_0 N_t$. Demand comes from manufacturing activities that exclusively use unskilled workers (whose only use is in these activities). Furthermore, all unskilled-labor demand will come from innovating firms, since those are the only ones producing in equilibrium. The Home leader produces output q_ℓ for the Home market and taking into account trade costs, the Home leader needs to produce τq_ℓ^* at Home in order to sell q_ℓ^* in the Foreign market.

The equilibrium condition in the unskilled-labor market can be analyzed starting with the demand for Home products, D_t, by Home and Foreign consumers $D_t = [q_\ell + \tau q_\ell^*] m_t$.Using equation (3.5), demand can be written as

$$D_t = \frac{cN_t \left[p_\ell^{-\sigma} + \tau \left(p_\ell^*\right)^{-\sigma}\right]}{P_t^{1-\sigma}} m_t.$$

Full employment of unskilled labor implies that $L_t = \theta_0 N_t = cN_t \left[p_\ell^{-\sigma} + \tau \left(p_\ell^*\right)^{-\sigma}\right] m_t / P_t^{1-\sigma}$. Dividing both sides by N_t yields a market size-adjusted full-employment condition for unskilled labor:

$$\theta_0 = \frac{c \left[p_\ell^{-\sigma} + \tau \left(p_\ell^*\right)^{-\sigma}\right]}{P_t^{1-\sigma}} m_t.$$

I can solve for c from equations (3.8) and (3.28) to get $c = \frac{\left[\rho + \phi \frac{n}{(1-\phi)}\right]}{\gamma_i} \frac{xe^{\rho T}}{\theta_0}$, which implies that the full-employment condition for unskilled labor is

$$\theta_0^2 = \frac{\left[\rho + \phi \frac{n}{(1-\phi)}\right] xe^{\rho T} \left[p_\ell^{-\sigma} + \tau \left(p_\ell^*\right)^{-\sigma}\right]}{\gamma_i P_t^{1-\sigma}} m_t.$$

The expressions $\left[p_\ell^{-\sigma} + \tau \left(p_\ell^*\right)^{-\sigma}\right] / P_t^{1-\sigma}$ and γ_i will depend on how broad (or narrow) patent breadth is and the concomitant pricing strategy. So, depending on whether the leader practices monopoly pricing, limit pricing or part limit pricing, the full-employment condition for unskilled labor can be rewritten as[8]

$$\theta_0^2 = \eta_i \left[\rho + \phi \frac{n}{(1-\phi)} \right] x e^{\rho T} \qquad i \in \{M, ML, L\} \tag{3.29}$$

where $\eta_M = \sigma - 1$; $\eta_{ML} = \left[(1/\alpha)^{-\sigma} + \tau\beta^{-\sigma} \right] / \left[(1 - \tau/\beta) \beta^{1-\sigma} + (1-\alpha)(1/\alpha)^{1-\sigma} \right]$ or $\eta_L = (1+\tau) / [2\beta - (\tau + 1)]$. These expressions depend on parameters of the model but what is important here is that a fall in the trade cost $(\tau \downarrow)$ has no effect on η_M, but causes a decrease in η_{ML} and η_L.

Equation (3.29) is the steady-state full-employment condition for unskilled labor that takes into account the steady-state R&D condition of profit maximizing firms. One of the implications of (3.29) is that if θ_0 increases (meaning that the relative wage of unskilled workers increases), the RHS has to increase as well. Given that the only variable term is the relative R&D difficulty x, this term has to increase. It follows as in section 2 that (3.29) can be represented as an upward-sloping curve in (x, θ_0) space. The intuition behind the upward slope is as follows: Suppose that there is a decline in the skilled wage w_H, making it less attractive for workers to acquire skills and increasing the supply of unskilled labor $(\theta_0 \uparrow)$. In steady-state equilibrium, any increase in the supply of unskilled labor must be matched by an increase in the demand for unskilled labor. But firms only want to hire more unskilled workers in production (the only activity where they are employed by assumption) if there is stronger consumer demand for their products. Stronger consumer demand increases the benefit from innovating and the initial fall in the skilled wage w_H decreases the cost of innovating. Profit-maximizing firms respond to these incentives by devoting more resources to R&D, resulting in a long-run increase in relative R&D difficulty x. Thus, to satisfy both labor-market clearing and R&D optimization conditions, any increase in the supply of unskilled labor $(\theta_0 \uparrow)$ must be matched by an increase in consumer expenditure, which stimulates R&D investment and serves to raise the long-run level of relative R&D difficulty x.

Turning to the description of skilled labor, it is used exclusively in the innovation sector. From equation (3.24), I have that $\dot{m}_t = \frac{(1+\kappa)^\phi m_t^\phi H_t}{a}$, so H_t can be expressed as $\frac{(\dot{m}_t/m_t)a}{(1+\kappa)^\phi \left(m_t^\phi / m_t \right)} = \frac{gam_t^{1-\phi}}{(1+\kappa)^\phi}$. The supply of skilled labor was described by equation (3.10), so market clearing implies that $\frac{\left(1-\theta_0^2\right)}{2} \left[e^{-nT} N_t \right] = \frac{gam_t^{1-\phi}}{(1+\kappa)^\phi}$. Dividing both sides by N_t, and using equation (3.25), I obtain the market size-adjusted steady-state full-employment

8 See The Appendix for details.

condition for skilled labor:

$$\frac{(1-\theta_0^2)}{2} = \left[e^{nT} g\right] x. \tag{3.30}$$

An increase in θ_0 decreases the LHS, so relative R&D difficulty x must decrease in response. It follows that equation (3.30) can be represented as an downward sloping curve in (x, θ_0) space. The intuition behind the downward slope is as follows: Suppose that there is a decline in the skilled wage w_H, making it less attractive for workers to acquire skills and decreasing the supply of skilled labor ($\theta_0 \uparrow$). In steady-state equilibrium, any decrease in the supply of skilled labor must be matched by a decrease in the demand for skilled labor. Since the steady-state rate at which new varieties are introduced $g = n/[(1-\phi)]$ is constant and given by parameter values, firms only hire less skilled workers in R&D (the only activity where they are employed by assumption) if R&D becomes relatively less difficult ($x \downarrow$). Thus, to satisfy market clearing for skilled labor, any decrease in the supply of skilled labor ($\theta_0 \uparrow$) must be matched by a decrease in the demand for skilled labor in R&D and this only occurs if R&D becomes relatively less difficult ($x \downarrow$).

It is important to notice that (3.30) is independent of τ, since τ only affects production that uses unskilled labor.

3.7. Steady-State Equilibrium Properties. I have managed to reduce the model to a system of two equations (3.29) – (3.30) in two unknowns (x, θ_0). The representation is identical to the one in Figure 1. The unskilled-labor condition (3.29) is globally upward-sloping and goes through the origin, while the skilled-labor condition is globally downward-sloping with strictly positive intercepts, so these curves have a unique intersection given by point A. The steady-state values of (x, θ_0) are therefore uniquely determined. Given that θ_0 is determined, w_H is uniquely determined by equation (3.8). These results imply that the model has a unique steady-state equilibrium.

The focus of the paper is on analyzing the steady-state equilibrium implications of trade liberalization ($\tau \downarrow$). The impact will depend on how broad (or narrow) patent breadth is and the corresponding price setting strategy producers follow.

If innovative firms receive broad patent breadth and $\beta > \tau/\alpha$, then Home leaders charge the monopoly price $1/\alpha$ in the Home market and the monopoly price τ/α in the Foreign market. Equation (3.29) becomes

$$\theta_0^2 = \eta_M \left[\rho + \phi \frac{n}{(1-\phi)}\right] x e^{\rho T}.$$

Notice that neither (3.29) nor (3.30) depend in this case on τ and the steady-state equilibrium is still given by point A in Figure 1. θ_0, x and w_H remain unchanged when τ falls.

If $\tau/\alpha > \beta > 1/\alpha$, then Home leaders practice part limit pricing, charge the limit price β in the Foreign market and the monopoly price $1/\alpha$ in the Home market. Equation (3.29) is then

$$\theta_0^2 = \eta_{ML}\left[\rho + \phi\frac{n}{(1-\phi)}\right] xe^{\rho T}$$

where η_{ML} is increasing in τ. This implies that if τ falls, θ_0 must decrease for any given value of x. Thus, the unskilled labor condition shifts down as illustrated in Figure 2 and there is a new intersection of the two curves given by point B. A decrease in τ leads therefore to a permanent decrease in θ_0 and a permanent increase in x. From (3.8), the permanent decrease in θ_0 is associated with a permanent increase in w_H.

Finally, if innovative firms receive narrow patent breadth and $\tau/\alpha > 1/\alpha > \beta$, then Home leaders charge the limit price β in both Foreign and Home markets. Equation (3.29) is then

$$\theta_0^2 = \eta_L\left[\rho + \phi\frac{n}{(1-\phi)}\right] xe^{\rho T}$$

where η_L is increasing in τ. This implies that if τ falls, θ_0 must decrease for any given value of x. Thus, the unskilled labor condition shifts down as illustrated in Figure 2 and there is a new intersection of the two curves given by point B. A decrease in τ leads therefore to a permanent decrease in θ_0 and a permanent increase in x. From (3.8), the permanent decrease in θ_0 is associated with a permanent increase in w_H.

In the new steady-state described by point B in Figure 2, θ_0 is lower suggesting that it is now more profitable to train in order to become a skilled worker. This increases the supply of skilled workers, as indicated by equation (3.10). To see the implications of a higher x, I take logs and differentiate the definition $x = am_t^{1-\phi}/N_t\,(1+\kappa)^{\phi}$ to obtain

$$\frac{\dot{x}_t}{x_t} = (1-\phi)\,\frac{\dot{m}_t}{m_t} - n \tag{3.31}$$

But given that $g \equiv \frac{\dot{m}_t}{m_t} = \frac{n}{(1-\phi)}$ in steady-state, x is constant over time. Thus, for x to permanently increase, the rate at which new varieties are introduced (and at which the economy grows), must temporarily increase above its steady-state level.

The results of this section are summarized in the following theorem:

THEOREM 2. *If firms receive narrow patent protection ($\tau/\alpha > \beta$), then trade liberalization that takes the form of a permanent reduction in trade costs ($\tau \downarrow$) leads to a permanent increase in the relative wage of skilled labor ($w_H/w_L \uparrow$), a permanent* *increase in the fraction of the population that chooses to acquire skills ($\theta_0 \downarrow$), and a temporary increase in the global innovation rate ($\frac{\dot{m}_t}{m_t} \uparrow$).*

On the other hand, if firms receive broad patent protection ($\beta > \tau/\alpha$), then trade liberalization that takes the form of a permanent reduction in trade costs ($\tau \downarrow$) leads to no change in the relative wage of skilled labor (w_H/w_L constant), no change in the fraction of the population that chooses to acquire skills (θ_0 constant), and no change in the global innovation rate ($\frac{\dot{m}_t}{m_t}$ constant).

The properties of this model when firms receive narrow patent protection (limit pricing and part limit pricing cases) are quite intuitive. When trade costs fall, firms earn higher profits from exporting their products and consequently their overall profits increase [$\tau \downarrow \Longrightarrow \pi \uparrow$ from equations (3.19) and (3.23)]. Because these profits are a reward for developing a new variety, it follows that when trade costs fall, firms have a stronger incentive to develop new varieties [$\tau \downarrow \Longrightarrow v_t \uparrow$ from equation (3.27)] and household's savings are channeled through financial markets towards R&D ventures. The demand by firms for skilled workers capable of doing R&D increases, bidding up the relative wage of skilled labor [$w_H/w_L \uparrow$]. When workers see that the reward for becoming skilled has gone up, more workers choose to undergo the training needed to acquire skills [$w_H/w_L \uparrow \Longrightarrow \theta_0 \downarrow$ from equation (3.8)], global R&D employment increases [$\theta_0 \downarrow \Longrightarrow [1-(\theta_0)^2]e^{-nT}N_t \uparrow$ from equation (3.10)] and the global economy experiences a faster rate of technological change [$x \uparrow \Longrightarrow g \equiv \frac{\dot{m}_t}{m_t} \uparrow$ from equation (3.31)]. The model highlights a potentially very important benefit of trade liberalization, namely, that it promotes technological change and economic growth.

Theorem 2 also establishes that trade liberalization does not always promote technological change. Whether or not trade liberalization promotes technological change depends on the strength of IPRs. When firms receive broad patent protection (IPRs are strong) and charge monopoly prices, then trade liberalization does not promote technological change, does not lead to any skill-upgrading and has no effect on relative wages. The key is that trade liberalization does not contribute to increasing overall firm profits when firms charge monopoly prices [$\tau \downarrow \Longrightarrow \pi$ constant, from equation (3.16)]. Firms earn higher profits from exporting π_ℓ^* because the price they charge is lower and more consumers demand their variety. But profits from domestic sales π_ℓ decrease to the same extent: the price they charge to locals is unaltered, but foreign exporters lower their prices, taking market share. In this symmetric scenario, these two effects cancel each other out, leaving $\pi_\ell + \pi_\ell^*$ unaffected. Since trade liberalization does not change the overall profits that firms earn from innovating, firms do not increase their R&D activities, the wage of skilled workers is not bid up and the fraction of workers that acquire skills does not increase. On the other hand, when patent breadth is narrow firms either practice limit pricing or part limit pricing and there are no price changes due to trade liberalization. A lower τ however, reduces production costs and increases the profit margin and overall profits, encouraging innovative work. These arguments apply equally to the results of section 2.

Regardless of whether innovations are vertical or horizontal, the impact trade has on profits (and growth) can be summarized by the mechanism present in two operating forces that oppose each other and it is their relative strengths that determine whether trade will have a pro-growth effect or not. One can be called the mark-up channel and the other the competition channel. The mark-up channel is the difference between price and marginal cost. The competition channel measures the impact trade has on firms' overall profits and market shares. In the monopoly pricing case, the mark-up channel is growth-neutral because it leaves profit margins unaffected since all trade costs are passed on to consumers. The competition channel is pro-growth in the export market and anti-growth in the local market, but they cancel each other out, so trade liberalization is growth-neutral. In the part limit pricing and limit pricing cases, the mark-up channel is pro-growth because lower trade costs imply lower costs for producers but the same price for consumers, while the competition channel is eliminated, so trade liberalization is pro-growth.

4. Concluding Comments

Trade liberalization in the models of Dinopoulos and Segerstrom (1999) and Baldwin and Forslid (2000) generates an unexplained puzzling result: trade promotes economic growth if innovations are vertical but has no effect on growth if innovations are horizontal. This puzzle holds by extension to the most commonly used versions of endogenous growth models with trade (EGMTs). In this paper I solve this puzzle and explain why trade liberalization promotes technological change in almost all vertical EGMTs (including Dinopoulos and Segerstrom) and why these results differ so radically to those found in similar EGMTs with horizontal innovation (including Baldwin and Forslid).

The reasons for this puzzle are the extreme assumptions on IPRs protection implicitly held in both vertical and horizontal EGMTs. Once these assumptions are relaxed, both models produce exactly the same results. The typical horizontal EGMT assumes broad patent breadth protection that allows leaders to charge monopoly prices, despite a competitive fringe of producers. This pricing strategy makes global profits independent of trade costs because leaders from both countries make the same price cuts in their exports markets if trade costs fall. Vertical innovation EGMTs on the other hand, implicitly assume narrow patent breadth protection, so given the presence of a competitive fringe, leaders practice limit pricing. The limit pricing strategy is independent of trade costs, but costs fall and profits in the export market increase if trade costs fall. This increases overall profits encouraging skilled-labor-intensive innovative work that accelerates technological change. I show that whether patent breadth is narrow or broad determines the pricing strategy. The pricing strategy is then what is crucial for determining the impact trade liberalization has on profits, wages and technological change.

5. Appendix

In this Appendix, calculations done to solve the model are spelled out in more detail.

5.1. Consumer Optimization in the Vertical Innovation Model. The across-industry static optimization problem at time t is

$$\max_{d_{\theta t}(\cdot)} \int_0^1 \left[\lambda^{j(\omega,t)} d_{\theta t}(\omega)\right]^\alpha d\omega \qquad \text{subject to} \qquad c_{\theta t} = \int_0^1 p_t(\omega) d_{\theta t}(\omega)\, d\omega.$$

This problem can be rewritten as the optimal control problem

$$\max_{d_{\theta t}(\cdot)} \int_0^1 \left[\lambda^{j(\omega,t)} d_{\theta t}(\omega)\right]^\alpha d\omega \qquad \text{s. t.} \qquad \dot{y}_{\theta t}(\omega) = p_t(\omega) d_{\theta t}(\omega),\ y_{\theta t}(0) = 0,\ y_{\theta t}(1) = c_{\theta t}.$$

where $y_{\theta t}(\omega)$ is a new state variable and the derivative is with respect to ω. The Hamiltonian function for this optimal control problem is

$$H \equiv \left[\lambda^{j(\omega,t)} d_{\theta t}(\omega)\right]^\alpha + \gamma_{\theta t}(\omega) p_t(\omega) d_{\theta t}(\omega)$$

where $\gamma_{\theta t}(\omega)$ is the costate variable. The costate equation $\partial H/\partial y_{\theta t} = 0 = -\dot{\gamma}_{\theta t}(\omega)$ implies that $\gamma_{\theta t}$ is constant across ω. $\partial H/\partial d_{\theta t} = \lambda^{\alpha j(\omega,t)} \alpha d_{\theta t}(\omega)^{\alpha-1} + \gamma_{\theta t} \cdot p_t(\omega) = 0$ implies that

$$d_{\theta t}(\omega) = \left(\frac{\lambda^{\alpha j(\omega,t)}\alpha}{-\gamma_{\theta t} \cdot p_t(\omega)}\right)^{1/(1-\alpha)}.$$

Substituting this back into the budget constraint $c_{\theta t} = \int_0^1 p_t(\omega) d_{\theta t}(\omega) d\omega$ yields

$$c_{\theta t} = \int_0^1 p_t(\omega) \left(\frac{\lambda^{\alpha j(\omega,t)}\alpha}{-\gamma_{\theta t} \cdot p_t(\omega)}\right)^{1/(1-\alpha)} d\omega = \left(\frac{\alpha}{-\gamma_{\theta t}}\right)^{1/(1-\alpha)} \int_0^1 \lambda^{\alpha j(\omega,t)/(1-\alpha)} p_t(\omega)^{(1-\alpha-1)/(1-\alpha)} d\omega.$$

Now $\sigma \equiv \frac{1}{1-\alpha}$ implies that $1 - \sigma = \frac{1-\alpha-1}{1-\alpha}$ and $\sigma - 1 = \frac{\alpha}{1-\alpha}$, so

$$\frac{c_{\theta t}}{\int_0^1 q_t(\omega) p_t(\omega)^{1-\sigma} d\omega} = \left(\frac{\alpha}{-\gamma_{\theta t}}\right)^{1/(1-\alpha)}$$

where $q_t(\omega) \equiv \lambda^{(\sigma-1)j(\omega,t)}$ is a measure of product quality. It immediately follows that the consumer demand function is

(3) $$d_{\theta t}(\omega) = \frac{q_t(\omega)p_t(\omega)^{-\sigma}c_{\theta t}}{P_t^{1-\sigma}}$$

where $P_t \equiv \left[\int_0^1 q_t(\omega)p_t(\omega)^{1-\sigma}\,d\omega\right]^{1/(1-\sigma)}$ is a quality-adjusted price index.

Substituting this consumer demand function back into the consumer utility function yields

$$u_{\theta t} = \left[\int_0^1 \lambda^{\alpha j(\omega,t)} d_{\theta t}(\omega)^{\alpha}\,d\omega\right]^{\frac{1}{\alpha}} = \left[\int_0^1 \frac{\lambda^{\alpha j(\omega,t)}\lambda^{(\sigma-1)\alpha j(\omega,t)}p_t(\omega)^{-\sigma\alpha}(c_{\theta t})^{\alpha}}{P_t^{(1-\sigma)\alpha}}d\omega\right]^{\frac{1}{\alpha}},$$

which simplifies to

$$u_{\theta t} = c_{\theta t}\left[\int_0^1 \frac{\lambda^{\sigma\alpha j(\omega,t)}p_t(\omega)^{-\sigma\alpha}}{P_t^{(1-\sigma)\alpha}}d\omega\right]^{\frac{1}{\alpha}} \quad \text{or} \quad \ln u_{\theta t} = \ln c_{\theta t} + \ln\left[\int_0^1 \frac{\lambda^{\sigma\alpha j(\omega,t)}p_t(\omega)^{-\sigma\alpha}}{P_t^{(1-\sigma)\alpha}}d\omega\right]^{\frac{1}{\alpha}}.$$

The individual household takes the prices and qualities of all products (and how they change over time) as given, so the last bracketed expression can be ignored in solving the household's dynamic optimization problem. This problem simplifies to:

$$\max_{c_{\theta t}} \int_0^{\infty} e^{-(\rho-n)t}\ln c_{\theta t}\,dt \qquad \text{subject to} \qquad \dot{a}_{\theta t} = w_{\theta t} + r_t a_{\theta t} - n a_{\theta t} - c_{\theta t},$$

where $a_{\theta t}$ represents the asset holding of the representative consumer in household θ at time t, $w_{\theta t}$ is the wage rate earned by the representative consumer and r_t is the market interest rate.

The Hamiltonian function for this optimal control problem is

$$H = e^{-(\rho-n)t}\ln c_{\theta t} + \gamma_t\left[w_{\theta t} + r_t a_{\theta t} - n a_{\theta t} - c_{\theta t}\right]$$

where γ_t is the relevant costate variable. The costate equation $-\dot{\gamma}_t = \partial H/\partial a_{\theta t} = \gamma_t\left[r_t - n\right]$ implies that

$$\frac{\dot{\gamma}_t}{\gamma_t} = n - r_t.$$

$\partial H/\partial c_{\theta t} = e^{-(\rho-n)t}\frac{1}{c_{\theta t}} - \gamma_t = 0$ implies that $e^{-(\rho-n)t}\frac{1}{c_{\theta t}} = \gamma_t$. Taking logs of both sides yields $-(\rho-n)t - \ln c_{\theta t} = \ln\gamma_t$ and then differentiating with respect to time yields

$$-(\rho-n) - \frac{\dot{c}_{\theta t}}{c_{\theta t}} = \frac{\dot{\gamma}_t}{\gamma_t} = n - r_t.$$

It immediately follows that

(5) $$\frac{\dot{c}_{\theta t}}{c_{\theta t}} = r_t - \rho.$$

5.2. Labor Markets for the Horizontal Innovation Model. Equation (55) can be obtained using the results of sections 3.3.1, 3.3.2 and 3.3.3.

In section 3.3.1 each leader charges monopoly prices, $\gamma_M \equiv 1-\alpha$ and

$$\frac{\left[p_\ell^{-\sigma}+\tau\left(p_\ell^*\right)^{-\sigma}\right]}{P_t^{1-\sigma}}=\frac{\left[\left(\frac{1}{\alpha}\right)^{-\sigma}+\tau\left(\frac{\tau}{\alpha}\right)^{-\sigma}\right]}{m_t\left(\frac{1}{\alpha}\right)^{1-\sigma}\left(1+\tau^{1-\sigma}\right)}=\frac{\alpha\left[\left(\frac{1}{\alpha}\right)^{1-\sigma}+\left(\frac{\tau}{\alpha}\right)^{1-\sigma}\right]}{m_t\left(\left(\frac{1}{\alpha}\right)^{1-\sigma}+\left(\frac{\tau}{\alpha}\right)^{1-\sigma}\right)}=\frac{\alpha}{m_t}=\frac{\sigma-1}{\sigma m_t}.$$

It follows that

$$\begin{aligned}\theta_0^2 &= \frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}\left[p_\ell^{-\sigma}+\tau\left(p_\ell^*\right)^{-\sigma}\right]}{\gamma_i P_t^{1-\sigma}}m_t=\frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}}{1-\alpha}\frac{\alpha}{m}m_t\\ &= \left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}(\sigma-1)\end{aligned}$$

that corresponds to equation (55) when $i=M$.

In section 3.3.2, each leader charges limit prices, $\gamma_L \equiv [2\beta-(\tau+1)]/2\beta$ and

$$\frac{\left[p_\ell^{-\sigma}+\tau\left(p_\ell^*\right)^{-\sigma}\right]}{P_t^{1-\sigma}}=\frac{\left[(\beta)^{-\sigma}+\tau(\beta)^{-\sigma}\right]}{2m_t\beta^{1-\sigma}}=\frac{\left[(\beta)^{1-\sigma}+\tau(\beta)^{1-\sigma}\right]}{2m_t\beta^{2-\sigma}}=\frac{(1+\tau)}{2m_t\beta}.$$

It follows that

$$\begin{aligned}\theta_0^2 &= \frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}\left[p_\ell^{-\sigma}+\tau\left(p_\ell^*\right)^{-\sigma}\right]}{\gamma_i P_t^{1-\sigma}}m_t=\frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}}{[2\beta-(\tau+1)]/2\beta}\frac{(1+\tau)}{2m_t\beta}m_t\\ &= \frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}}{[2\beta-(\tau+1)]}(1+\tau)\end{aligned}$$

that correponds to equation (55) when $i=L$.

In section 3.3.3 each leader charges a monopoly price in the local market and a limit price in the export market, $\gamma_{ML} \equiv \left[\left(1-\frac{\tau}{\beta}\right)\beta^{1-\sigma}+(1-\alpha)\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]/\left[\beta^{1-\sigma}+\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]$ and

$$\frac{\left[p_\ell^{-\sigma}+\tau\left(p_\ell^*\right)^{-\sigma}\right]}{P_t^{1-\sigma}}=\frac{\left[\left(\frac{1}{\alpha}\right)^{-\sigma}+\tau(\beta)^{-\sigma}\right]}{\left[m_t\left[\beta^{1-\sigma}+\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]\right]}.$$

It follows that

$$\begin{aligned}\theta_0^2 &= \frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}\left[\beta^{1-\sigma}+\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]}{\left[\left(1-\frac{\tau}{\beta}\right)\beta^{1-\sigma}+(1-\alpha)\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]}\frac{\left[\left(\frac{1}{\alpha}\right)^{-\sigma}+\tau(\beta)^{-\sigma}\right]}{\left[\beta^{1-\sigma}+\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]}\\ &= \frac{\left[\rho+\phi\frac{n}{(1-\phi)}\right]xe^{\rho T}\left[\left(\frac{1}{\alpha}\right)^{-\sigma}+\tau(\beta)^{-\sigma}\right]}{\left[\left(1-\frac{\tau}{\beta}\right)\beta^{1-\sigma}+(1-\alpha)\left(\frac{1}{\alpha}\right)^{1-\sigma}\right]}\end{aligned}$$

that correponds to equation (55) when $i = ML$.

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PAPER 2

Trade With Heterogenous Firms and Workers

Damián Migueles Chazarreta

ABSTRACT. I present an endogenous growth model with trade, relative wages and Schumpeterian growth. Firms improve upon existing products and intra-industry heterogeneity determines which markets they penetrate. What distinguishes this paper from the earlier literature is that wage inequality is addressed in a heterogeneous firm setting with quality ladders. The model finds support for trade as a channel for increasing wage inequality despite the absence of a Stolper-Samuelson mechanism.

JEL Classification: F10, F12, F43, D31, O31, O41

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1. Introduction

There is well documented evidence that the demand for less skilled labor has decreased in recent decades.[1] This decrease has resulted in an increase in the skilled-wage premium in several countries, including the U.S.[2] The skilled-wage premium has also increased in Europe, although less dramatically (see Berman et al., 1998).

The early attempts to explain these labor-market developments focused on the role that global market integration could have played in explaining the rise in wage inequality. Moreover, empirical findings[3] indicating the negative correlation between the volume of imports and the relative demand for unskilled labor, suggest that the Stolper-Samuelson (1941) theorem could be the driving force behind these results. This theorem states that a decline in the relative price of a good reduces the return of the factor used intensively in its production. In a North-South trade scenario with skilled-labor intensive industries in the North and unskilled-labor intensive industries in the South, the Stolper-Samuelson mechanism implies that increased trade between these two regions puts downward pressure on the relative wage of unskilled workers in the North.[4]

There are two reasons why this mechanism has failed to convince researchers. First, trade between advanced and less advanced countries is very limited.[5] Second, for this mechanism to work, trade must induce changes in the relative prices of the goods produced by skilled and unskilled-labor intensive industries. The evidence, however, shows that U.S. domestic relative prices (of imported in terms of exported goods) are roughly constant, in spite of increasing volumes of trade.[6] In addition, it has been noted that skilled labor as a fraction of total employment has increased in the U.S. and this skill upgrade by workers has occurred mostly *within* industries as opposed to *between* industries, which is the type of reallocation of labor associated with changes in relative

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[1] Johnson (1997) presents evidence on the decline of less skilled labor demand in the U.S. Marvin H. Kosters (1994), Gary Burtless (1995), Richard B. Freeman (1995), and David J. Richardson (1995) provide overviews of the empirical evidence.

[2] See for instance Katz and Murphy (1992); Murphy and Welch (1992); and Juhn, Murphy, & Pierce (1993) for an analysis of the widening of the US wage structure during the 1980s. Autor, Katz and Kearney (2008) provide further evidence for the period 1963-2005 for the US.

[3] Murphy and Welch (1992) argue that trade has increased wage differentials between high-school and college graduates by about 4 to 5 percent. Borjas and Ramey (1994), using U.S. time series data, show that net imports of durable goods (as a percentage of GDP) and the relative wage of unskilled workers are negatively correlated.

[4] Feenstra (2008) provides a discussion on the relation between trade and relative wages in Ricardian, Hecksher-Ohlin and "new-trade" models á la Krugman.

[5] The value of imports of manufactures from less advanced countries constitute less than 3% of OECD GDP (Woods, 1998). Krugman (2000) argues that trade between OECD and non-OECD countries is too small to have an impact on relative wages.

[6] Dinopoulos and Segerstrom (1999) go through the evidence in their introduction.

wages in a Heckscher-Ohlin-Samuelson framework.[7] This (lack of) evidence has been taken as support for the skilled-biased technical change hypothesis and several studies have supported it.[8] Some authors have also characterized the wage inequality rise of the 1980s as a result of non-market factors such as falling real minimum wages and eroding bargaining power of institutions such as labor unions.[9] Other authors suggest that trade could increase wage inequality, but only if trade promotes skilled-biased technical change.[10]

One of the first models that reconciles the empirical evidence with a theory of international trade is Dinopoulos and Segerstrom (1999). They propose a quality-ladders endogenous growth model with trade as in Grossman and Helpman (1991) but with a Schumpeterian creative-destruction mechanism that makes old products obsolete and encourages firms to do costly skilled-labor intensive R&D, in order to improve upon existing products and become a leader in the local and foreign markets. In their model, trade liberalization increases the potential profits from exporting and makes innovations more profitable, which in turn increases the demand for resources in the R&D sector. However, all producing firms are identical and they could therefore not account for the firm heterogeneity found in empirical work. They also assume that successful innovations are always exported and leave fixed costs for producing and exporting out of their analysis, underestimating the costs involved in production and exporting activities.

The pioneering work of Melitz (2003), Bernard, Eaton, Jensen and Kortum (2003), Helpman, Melitz and Yeaple (2004), Melitz and Ottaviano (2005), Yeaple (2005) and Baldwin (2005) has caught the attention of trade economists and has put focus on intra-industry firm heterogeneity, accounting for many new firm-level empirical facts[11]. Although this literature, also known as "new-new" trade theory, is expanding rapidly in several directions, it has typically worked with one factor only, being unable to address questions about relative wages.[12]

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[7] See Berman et al. (1994).

[8] See Krugman and Lawrence (1994), Berman et al. (1994), Davis (1998) and Krusell et al. (2000)

[9] See Katz and Autor (1999), Goldin and Katz (2001) and Acemoglu (2002) for overviews. Berman, Bound, and Machin (1998) and Machin and Van Reenen (1998) make international comparisons. Autor et al. (2008) finds little support for these nonmarket claims in the data.

[10] Acemoglu (2003) propose a North-South model where skill-complement innovations are made more profitable as trade liberalizes. Neary (2002) and Thoenig and Verdier (2003) propose "defensive innovations" models between similar countries. Epifani and Gancia (2007) study the case where economies of scale increase the demand for skilled labor between similar countries.

[11] Clerides, Lach and Tybout (1998) found that many firms do not export their products and it is the most productive firms that tend to export. See also Tybout (2003) for a survey.

[12] One exception is Bernard, Redding and Schott (2007) who present a Heckscher-Ohlin model with two factors, different factor intensities and heterogeneous firms. But unlike in this paper where

The purpose of this paper is to introduce the role of trade openness as a cause for wage dispersion in the new-new trade literature and I show that this can be done without affecting the relative prices of traded final goods. In contrast to the aforementioned new-new trade literature that is "static" with zero productivity growth rate in steady-state, the model presented here is dynamic, allowing me to study the impact trade liberalization has on the growth rate of the economy. Another distinguishing feature is that here, trade is not driven by differences in factor endowments or in unit labor requirements (the two countries are identical, including their relative endowments); instead, the direction of trade will be determined by financial markets and successful R&D efforts. Whether any firms in an industry export or not will depend on who has innovated most recently. This paper also contributes to the literature on trade and growth by being the first endogenous growth model with quality ladders, trade with two factors and heterogeneous firms.[13]

The main results of this paper are twofold: trade liberalization increases wage inequality, and it contributes to general skill upgrading in the economy. These results are derived for the first time from a Melitz-type model where all the standard results of the new-new trade literature hold.

The model consists of two identical countries equally endowed with two factors: skilled and unskilled labor. Skilled labor is endogenously supplied: individuals can undergo a costless and unpaid training period to become skilled workers. In equilibrium, only those individuals with a sufficiently high ability level will find it profitable to undergo the training period, given the prevailing relative wage and their ability, and will constitute the supply of skilled labor. Each country has a continuum of structurally identical industries where firms produce final consumption goods. Firms within each industry participate in skilled-labor intensive R&D races: they try to improve upon the quality of the product of its industry in order to become the quality leader of its industry. Once a quality race is won, productivity in the unskilled-labor intensive manufacturing sector is revealed to successful firms. If firms are sufficiently productive, they will be able to overcome implementation costs associated with production in the local and foreign markets. This implies that quality leaders, depending on how productive they turn out to be in manufacturing, have three options: they either shut down production, produce for the local market only, or produce for both the local and foreign markets.

R&D is the skill-labor activity, they assume the same skill-labor intensities in manufacturing and R&D activities.

[13] Haruyama and Zhao (2009) present a Melitz-type model with quality ladders but without a skill-labor intensive R&D sector. In their model, trade liberalization has no effect on wage inequality.

A quality innovation will give the innovating firm the right to exclusively produce and sell its production in the markets it manages to penetrate.[14] However, the patent of an incumbent leader expires, becomes common knowledge and its product can be competitively produced, once it is leapfrogged by an innovator that also manages to sell in that market. This means that market power is lost only when an innovation is introduced in that market. Thus, if an innovation occurs in the market where the current leader comes from and the new quality leader only manages to penetrate the local market, the second best quality produced by the old leader can still be exported.

Compared to the previous literature on quality-ladder models with trade, this paper presents a model that explains why not all state-of-the-art quality products are traded, but might still be produced in the local market. This feature of the model captures the fact that export status does not only depend on quality: sunk costs associated to implementation in the destination market affect also the ability to export. So in addition to heterogeneity in quality, as in all quality-ladder models, there is an additional dimension of heterogeneity based on productivity differences that determine firms' export status.

This model is consistent with the results of new-new trade models where heterogeneous firms' exports depend on their productivity. These models, however, do not analyze the effects trade has on relative wages because there are no permanent reallocation of factors of production due to trade liberalization and there is typically one factor only in those models. The model has also a steady-state growth rate without scale effects as in Gustafsson and Segerstrom (2010) and Haruyama and Zhao (2009).

The rest of the paper is organized as follows: section 2 presents the dynamic general equilibrium model, section 3 solves the model for the steady-state equilibrium and section 4 concludes.

2. The Model

In this section I present a dynamic general equilibrium model with trade and analyze the balanced growth path properties. The model consists of two symmetric trading economies (Home and Foreign) whose agents have the same preferences and make identical decisions. Given this symmetry, I will focus on the decisions made by consumers and firms in one of the two economies.

The assumptions on consumer preferences and the skill-acquisition process are similar to those in Dinopoulos and Segerstrom (1999) but the rest of the model differs in several aspects: i) Firms are heterogeneous in their production costs and there are

[14] For both non-exporting and exporting quality leaders, we exclude the possibility of outsourcing or franchising.

sunks costs associated with production; ii) firms compete by setting prices instead of a Cournot quantity competition and iii) I assume that patent protection is narrow and market specific, instead of assuming that only state of the art products are protected.

2.1. Consumption. There is a continuum of households in each country indexed by ability $\theta \in [0;1]$. All members of household θ have the same ability level equal to θ, and all households have the same number of members at each point in time. Each household is modeled as a dynastic family whose size grows over time at an exogenously given rate $n > 0$. Each individual member of a household lives forever. Letting N_0 denote the number of members of each household at time $t = 0$, the population size in each country at time t is $N_t = N_0 e^{nt}$. I assume that each household shares its income among its members so that consumption expenditure is evenly spread.

The optimization problem of a household with ability θ is

$$\max_{q_\theta} U_\theta = \int_0^\infty N_0 e^{-(\rho-n)t} \ln [u_\theta (t)] \, dt \tag{2.1}$$

subject to the following constraints:

$$\ln u_\theta (t) = \int_0^1 \ln \left[\Sigma_j \lambda^j q_\theta (j, \omega, t)\right] d\omega \tag{2.2}$$

$$c_\theta (t) = \int_0^1 \left[\Sigma_j p (j, \omega, t) \, q_\theta (j, \omega, t)\right] d\omega \tag{2.3}$$

$$W_\theta + Z_\theta = \int_0^\infty N_0 c_\theta (t) \, e^{nt} e^{-R(t)} dt. \tag{2.4}$$

Equation (2.1) is the discounted utility of a household with ability θ where $\rho > n$ is the subjective discount rate. $u_\theta (t)$ is the instantaneous utility of an individual; where $q_\theta (j, \omega, t)$ denotes quantity consumed by an individual with ability θ of a good with j improvements in its quality in industry $\omega \in [0, 1]$ at time t. The parameter $\lambda > 1$ captures the size of each quality improvement. λ^j is increasing in j, capturing the idea that consumers have a preference for higher-quality products. $c_\theta (t)$ is per capita consumption expenditure of a consumer with ability θ at time t. The last equation is an intertemporal budget constraint where W_θ is the household's discounted wage income and Z_θ is the value of the household's financial assets. Its right-hand-side (RHS) equals the discounted value of a household's consumption from time t to infinity, and $R(t) \equiv \int_0^t r(s) \, ds$ is the market discount factor with $\dot{R}(t) = r(t)$ denoting the instantaneous interest rate at time t.

The maximization problem of the household can be solved in two steps.[15] First, maximizing subutility (2.2) subject to the expenditure constraint (2.3) yields a unit elastic demand function for the product in each industry with the lowest-quality adjusted price. Because all products within an industry are perfect substitutes, only the product with the lowest quality adjusted price is purchased.

The second step is to maximize the household´s discounted utility (2.1) subject to its intertemporal budget constraint (2.4). The solution to this problem delivers the standard Euler equation

$$\dot{c}_\theta (t) / c_\theta (t) = r(t) - \rho. \tag{2.5}$$

I solve the model for a steady-state equilibrium and I will therefore omit the time index "t" on variables with steady-state values unless necessary. In steady-state, I will have that wages, output, prices and consumption per capita are constant over time, implying that the market interest rate $r(t)$ must be equal to the subjective discount rate ρ.

2.2. Endogenous Skill Acquisition. All individuals of a household with ability level θ can undergo a training or apprenticeship period T and after that, emerge as skilled workers and earn the wage rate $(\theta - \sigma) w_H$ for the remaining of their lifetime[16]. The alternative is to remain an unskilled worker and earn the wage rate w_L. For simplicity, I assume that the only opportunity cost of becoming a skilled worker is the discounted value of forgone unskilled wage income. An individual born at time t within a household with ability θ will therefore undergo a training period T and become a skilled worker if and only if

$$\int_t^\infty e^{-[R(s)-R(t)]} w_L ds \leq \int_{t+T}^\infty e^{-[R(s)-R(t)]} (\theta - \sigma) w_H ds. \tag{2.6}$$

The left-hand-side (LHS) of this inequality equals the discounted wage income of an individual earning the unskilled wage rate from time t to ∞. The RHS equals the discounted wage income of an individual earning zero income from time t to time $t+T$ and earning the skilled wage rate from time $t+T$ to ∞.

Given that only the RHS of (2.6) is increasing in θ, there exists an ability level θ_0 such that equation (2.6) holds as an equality. θ_0 works as a threshold level: all individuals with $\theta < \theta_0$ remain unskilled, but the others undergo training, entering the labor market after that as skilled workers. Setting (2.6) to hold as an equality and

[15] See Appendix A for details.

[16] The parameter $\sigma \in (0,1)$ just captures the fact that regardless of the wage rate, not all workers are capable of becoming skilled workers.

solving for the steady-state value of θ_0 delivers

$$\theta_0 = e^{\rho T}\left(w_L/w_H\right) + \sigma \tag{2.7}$$

meaning that the household members will become skilled if $\theta > \theta_0$. So skill acquisition increases with the skill premium (w_H/w_L) and decreases with the length of the apprenticeship period T.

Given that a share θ_0 of the population will remain unskilled, I can write down the supply of unskilled workers as:

$$L_t = \theta_0 N_t. \tag{2.8}$$

The remaining share $(1-\theta_0)$ are either skilled workers doing innovative work or unskilled workers undergoing training. In this subgroup, the skilled workers are those individuals born before $t-T$:

$$\int_{-\infty}^{t-T} n\left(1-\theta_0\right) N_s ds = \left(1-\theta_0\right) e^{-nT} N_t.$$

The average skill level of those workers with ability $\theta \in (\theta_0, 1)$ that have finished training equals $\frac{\theta_0-\sigma}{2} + \frac{1-\sigma}{2} = \frac{\theta_0+1-2\sigma}{2}$. The supply of skilled workers measured in efficiency units is then

$$H_t = \left(\frac{\theta_0 + 1 - 2\sigma}{2}\right)\left(1-\theta_0\right)\left[e^{-nT}N_t\right]. \tag{2.9}$$

Equations (2.7), (2.8) and (2.9) clearly show that if the steady-state value of θ_0 decreases, that must be accompanied by an increase in the relative wage of skilled workers and a relative increase in the supply of skilled workers.

2.3. R&D Races. A firm i which engages in a R&D race in industry ω at time t and discovers the next higher-quality product with instantaneous probability $I_i(\omega, t)$, uses skilled labor and incurs the following R&D cost

$$w_H F_R X(\omega, t) I_i(\omega, t), \tag{2.10}$$

where F_R is a cost parameter for doing R&D and $X(\omega, t)$ captures the difficulty of conducting R&D.

By instantaneous probability (or Poisson arrival rate) I mean that $I_i(\omega, t)\, dt$ is the probability that a firm i discovers the next higher-quality product by time $t + dt$ conditional on not having innovated by time t, where dt is an infinitesimal increment of time. I assume that the returns to R&D investments are independently and identically distributed across firms, industries and time, implying that the industry-wide instantaneous probability of innovating in industry ω at time t is $I(\omega, t) = \Sigma_i I_i(\omega, t)$ at

Home and $I^*(\omega,t) = \Sigma_i I_i^*(\omega,t)$ in Foreign. $I(\omega,t)$ can be interpreted as the industry-wide instantaneous probability of innovating in industry ω at time t. The arrival of innovations in each industry is therefore governed by a counting process whose intensity equals $I(\omega,t) + I^*(\omega,t)$. Symmetry implies that $I(\omega,t) = I^*(\omega,t)$. Following Segerstrom (1998), I will assume that R&D starts off being equally difficult in all industries [$X(\omega;0) = X_0$ for all ω where $X_0 > 0$ is a constant] and grows over time according to:

$$\frac{\dot{X}(\omega,t)}{X(\omega,t)} = \mu\left[I^*(\omega,t) + I(\omega,t)\right]. \tag{2.11}$$

This specification indicates that new quality improvements become more difficult to discover as time goes by and helps me rule out scale effects associated with a growing population. Scale effects that imply that larger economies grow faster are at odds with the empirical evidence[17].

R&D is financed by savings of the households. Because there is a continuum of industries with simultaneous R&D races, households can completely diversify the industry-specific risk and earn the equilibrium interest rate r.

I will solve the model for a symmetric steady-state equilibrium where both Home and Foreign innovation rates are constant over time and do not vary across industries, that is, $I(\omega,t) = I$ and $I^*(\omega,t) = I^*$ for all ω and t. It follows from (2.11) that X does not vary across industries: $X(\omega;t) = X_t$ for all ω and t.

2.4. Product Markets. Each industry is indexed by $\omega \in [0,1]$ and the total measure of industries in the world is equalized to one. Firms engage in R&D races to become the "quality leader" of their industry. Firms that do not produce the state-of-the-art quality are called "quality followers". Once a follower discovers the next higher-quality product, its productivity level will determine whether this firm would be able to implement the innovation in the local market, in both local and foreign markets, or in none of them. If production takes place, the leading firm will manufacture the final consumption good of its industry using unskilled labor only, according to a constant returns to scale technology represented by the following unit cost function,

$$a(\omega) + f \tag{2.12}$$

where f is the marginal cost of followers for producing the second-best quality and a is a firm-specific productivity parameter that will be discussed below. This specification

17 See Jones (1995 a,b) for a discussion of scale effects in endogenous growth models. Venturini (2010a) shows that semi-endogenous growth models have better empirical support than the other strands of Schumpeterian theory, especially for knowledge-intensive industries. Venturini (2010b) also presents evidence that innovation functions characterized by the increasing difficulty of R&D activity fit US data better.

implies that the marginal cost of producing the second best quality (f) is lower than the marginal cost of producing the highest quality available in the market.

A firm that innovates does not automatically produce because for implementing an innovation in the local market, firms have to incur sunk costs related to marketing, distribution, adaptation, etc. that I will denote $w_H X_t F_L$. F_L is a given parameter and $X_t F_L$ can be thought as the units of skilled labor required for local market implementation activities. For producing for the foreign market, the sunk costs that firms incur are $w_H X_t F_E$. Skilled labor is the only input used in these activities and only sufficiently cost-effective firms may overcome these sunk costs. Since exporting implies additional costs to those producing for the local market I assume that $F_E > F_L$.

Firms' producing and exporting status will be determined by the productivity parameter $a \equiv a(\omega)$ drawn from a Pareto density function $g(a)$ with support $[0, \bar{a}]$, that is,

$$G(a) \equiv \int_0^a g(a)da = \left(\frac{a}{\bar{a}}\right)^k, a \in [0, \bar{a}]$$

where $k > 0$, $\bar{a} > 0$ and $G(a)$ is the corresponding Pareto cumulative distribution function[18]. I assume that once drawn, the productivity parameter a for a newly improved quality is time invariant. I follow Gustafsson and Segerstrom (2010) and Baldwin and Robert-Nicoud (2008) by assuming that this dimension of heterogeneity follows a Pareto distribution. There is evidence (Del Gatto, 2006) that the Pareto distribution is a good approximation.

Heterogeneity in a generates three types of innovating firms within an industry: leaders that decide to shut down production (high a), leaders producing for the local market only (intermediate a) and leaders that produce for the local market and also export (low a). For this purpose, I define the boundary values a_L, a_E that satisfy

$$\bar{a} > a_L > a_E > 0 \quad \text{for all } t$$

where a_L is the boundary value at which the firm is indifferent between selling in the local market only (incurring the additional sunk cost $w_H X_t F_L$) and shutting down production, and a_E is the boundary value at which the firm is indifferent between selling in the local market only and incurring the additional sunk cost $w_H X_t F_E$ to export its variety.

If production takes place, a quality leader will receive a market-specific patent. By market-specific, I mean that the patent expires in a particular market when a quality follower discovers and implements the next higher-quality product in the market where

[18] Usually the Pareto distribution is defined by $P(X > x) = (x/\bar{x})^{-k}$. Substituting $a = 1/x$ and $\bar{a} = 1/\bar{x}$ yields $G(a) = (a/\bar{a})^k$.

the leader operates. In similar Schumpeterian growth models with trade (Dinopoulos and Segerstrom, 1999; Haruyama and Zhao, 2009) there are perfect international spillovers so the second-best quality becomes publicly available once a new improvement is discovered, no matter where. The absence of these spillovers in this model means that a leader maintains its incumbent position as long as a better quality is not sold in that market. A Home firm with incumbent position in the Home and Foreign markets might therefore lose its market power in Home but maintain it in Foreign if a Home follower innovates but does not manage to export. Alternatively, he might lose his incumbent position in Foreign while keeping it in Home if a Foreign follower manages to innovate but does not manage to export to Home. Incumbents can therefore lose one or two markets, depending on how cost-effective the new leader turns out to be.

To sum up, a successful innovation (one that will be produced) can be subdivided into two, mutually exclusive events: i) The new product is sold in the local market only; and ii) the new product is also exported. Given that innovations occur in all industries; in particular, there will be three different possible states for an industry: A_+, A_- and B. The description of the industry types is the following:[19]

A_+ : The local leader also exports.
A_- : The local leader and the exporting leader are different firms from the same country (the exporting leader's quality is one step below the local leader's).
B : No firm exports (there is a different local leader for each country).

Symmetry implies that 50% of all industries have a Home leader. In addition, given that events previously described occur in both countries and the model is symmetric, I will talk about an industry type at the whole-economy level instead of at the country-level.

2.4.1. *Industry Dynamics.* The two countries are structurally identical, implying that half of all industries belong to the Home country and the other half to the Foreign country. The industry types change from one state to another if any of these four distinct events occur:

$IG(a_E)$: a Home follower innovates and manages to export.
$I^*G(a_E)$: a Foreign follower innovates and manages to export.
$I[G(a_L) - G(a_E)]$: a Home follower innovates but only manages to produce for the local market.
$I^*[G(a_L) - G(a_E)]$: a Foreign follower innovates but only produces for the local market.

[19] See Table 1.

An A_+ industry will remain in that state if any follower in that industry (regardless of location), innovates and also manages to export, which occurs with instantaneous probability $IG(a_E) + I^*G(a_E)$. On the other hand, if the leader is a Foreign firm and a Home firm innovates but only manages to produce locally (instantaneous probability $I[G(a_L) - G(a_E)]$) the resulting industry-type is the B-type. If the leader is a Home firm instead, the outcome is a A_- industry type. Given that 50% of all A_+ industries have a Home leader, innovations that are only implemented in the local market change the industry structure to A_- with instantaneous probability $\frac{1}{2}I[G(a_L) - G(a_E)]$ and change the industry structure to B with instantaneous probability $\frac{1}{2}I[G(a_L) - G(a_E)]$. The same reasoning applies for innovations occurring in the Foreign market.

All transitions are described in Table 1; where the first column describes the initial state of an industry; the second all three distinct events that might affect an industry; and the third the outcome.

Initial State	Instantaneous Probability of Transition	New State
A_+	$IG(a_E) + I^*G(a_E)$	A_+
	$\frac{1}{2}I[G(a_L) - G(a_E)] + \frac{1}{2}I^*[G(a_L) - G(a_E)]$	B
	$\frac{1}{2}I[G(a_L) - G(a_E)] + \frac{1}{2}I^*[G(a_L) - G(a_E)]$	A_-
A_-	$IG(a_E) + I^*G(a_E)$	A_+
	$\frac{1}{2}I[G(a_L) - G(a_E)] + \frac{1}{2}I^*[G(a_L) - G(a_E)]$	B
	$\frac{1}{2}I[G(a_L) - G(a_E)] + \frac{1}{2}I^*[G(a_L) - G(a_E)]$	A_-
B	$IG(a_E) + I^*G(a_E)$	A_+
	$I[G(a_L) - G(a_E)] + I^*[G(a_L) - G(a_E)]$	B

Table 1: Industry Dynamics

For establishing the measure of each industry, I can divide all industries into A_+ types and non A_+ types. If the measure of A_+ industries is denoted by N_{A_+} and the measure of non A_+ by $\bar{N}_{A_+}$ I have that the flow out of and into A_+ industries can easily be deduced from Table 1 and is given by

$$\dot{N}_{A_+} = \bar{N}_{A_+}[G(a_E)][I^* + I] - N_{A_+}[G(a_L) - G(a_E)][I^* + I]$$

where $\dot{N}_{A_+}$ is the time derivative of N_{A_+} with respect to t.

In steady-state I have that $\dot{N}_{A_+} = 0$, so

$$\frac{\bar{N}_{A_+}}{N_{A_+}} = \frac{[G(a_L) - G(a_E)]}{[G(a_E)]}.$$

Using the properties of the Pareto distribution and $\bar{N}_{A_+} + N_{A_+} = 1$, the steady-state values of $\bar{N}_{A_+}$ and N_{A_+} are

$$\bar{N}_{A_+} = \frac{a_L^k - a_E^k}{a_L^k};\ N_{A_+} = \frac{a_E^k}{a_L^k}. \tag{2.13}$$

These results indicate that the smaller the gap between a_L and a_E, the larger the measure of the A_+ industries. In the limit, if $a_L^k = a_E^k$, then all industries are A_+ types.

The size of the B industries can also be determined following the same procedure:

$$\dot{N}_B = \bar{N}_B \frac{1}{2} \left[I^* + I \right] \left[G(a_L) - G(a_E) \right] - N_B \left[I^* + I \right] \left[G(a_E) \right],$$

which implies that

$$\begin{aligned} N_B &= \frac{[G(a_L) - G(a_E)]}{[G(a_L) + G(a_E)]} \\ &= \frac{a_L^k - a_E^k}{a_L^k + a_E^k} \end{aligned} \tag{2.14}$$

which is increasing in a_L and decreasing in a_E.

Given that $N_B + N_{A_+} + N_{A_-} = 1$, the measure of the A_- industries is

$$N_{A_-} = \frac{a_E^k}{a_L^k} \frac{\left[a_L^k - a_E^k \right]}{\left[a_E^k + a_L^k \right]}, \tag{2.15}$$

which is increasing in a_L, if a_L is not so large with respect to a_E and decreasing otherwise.

2.5. Profits and Trade. There is a continuum of industries in each country indexed by $\omega \in (0, 1)$ and in each industry, firms produce final consumption goods using unskilled labor only. There are two barriers for trade. First, there is an "iceberg" trade cost τ, such that $\tau > 1$ units of goods must be shipped in order for one unit to arrive to the other country. Second, given that there are additional sunk costs associated with exporting, only sufficiently productive firms that can overcome the overall trade costs will become exporters.

Producing quality leaders face competition from below in any market by a competitive fringe of followers that can produce the second-best quality consumer goods that are not protected by patents. Leaders will compete with these followers at home and abroad in a Bertrand fashion by setting prices[20].

Given that there will be profits from selling to foreigners and locals, let us define Q^* as the output a Home leader (that made a draw $a < a_E$) exports to Foreign consumers and Q the output the Home leader sells at Home. Denote the price that the Home exporting leader charges for selling to foreign consumers by $p^*(a)$ and $p(a)$ the price the leader charges in the local market.[21]

[20] A Cournot quantity competing setting delivers similar results, but there will then be a competitive fringe of producing followers and output will depend on the productivity draw allowing for large and small leading firms.

[21] From now on, we will skip the (a) notation in the price function, unless required.

Since the marginal cost of production at Home for a leader is given by $a+f$ and that τ units of good have to be exported for each unit consumed abroad, the profit function for a leader from selling abroad is

$$\pi^* (a) = p^* Q^* - \tau (a+f) Q^* \qquad a \in (0, a_E).$$

Recall that the marginal cost of followers f was lower than the marginal cost of leaders $a+f$. But leaders will still be able to charge a price higher than their marginal cost since consumers choose the product with the lowest quality adjusted price. That is, if followers charge f per unit, consumers will buy the leader's product if $a+f < p^* < f\lambda$. Moreover, assume that in the borderline case $p^* = f\lambda$ where consumers are indifferent, they only buy from the firm selling the latest innovation. The profit flow is therefore maximized by charging the limit price $p^* = f\lambda$, implying that only the highest quality product is produced and sold. The value of total output at Foreign is therefore

$$c^* N_t^* = p^* Q^* = f\lambda Q^*. \tag{2.16}$$

If I solve for Q^*, the profit function for the exporting leader can be rewritten as

$$\pi^* = c^* N_t^* \left[1 - \frac{\tau (a+f)}{f\lambda}\right] \qquad a \in (0, a_E) \tag{2.17}$$

and the total output exported is

$$Q^* = \frac{c^* N_t^*}{f\lambda}. \tag{2.18}$$

Since incumbent leaders face segmented markets and do not incur any trade costs when selling to local consumers, the profit function for leader selling at Home differs with respect to the profit function for an exporting leader only in the absence of the trade costs τ. The pricing strategy is also the same: if they charge $p > f\lambda$, profits are zero, hence they charge the limit price $f\lambda$. Their profits are

$$\pi = cN_t \left[1 - \frac{a+f}{f\lambda}\right] \qquad a \in (0, a_L) \tag{2.19}$$

and total output sold locally is

$$Q = \frac{cN_t}{f\lambda}. \tag{2.20}$$

Notice that although output is independent of the draw a and the iceberg trade cost τ, profits will depend on both: equations (2.17) and (2.19) show that profits are decreasing in a and τ. It is also important to remark that changes in trade costs do not affect relative prices (the relative price of imported to locally produced goods) since leaders charge the limit price $f\lambda$ for all τ, given that they are price constrained by the competitive fringe of followers.

A leader obtains profits from both markets if it is in an A_+industry type, where the exporting leader is also the local leader. The global profit flow it gets is then

$$\pi^* + \pi = \Pi = c^* N_t^* \left[1 - \frac{\tau (a+f)}{f\lambda}\right] + cN_t \left[1 - \frac{a+f}{f\lambda}\right] \qquad a \in (0, a_E).$$

Structural symmetry across Home and Foreign implies that $c = c^*$ and $N_t = N_t^*$; hence

$$\Pi = \frac{cN_t}{f\lambda} \left[2f\lambda - (a+f)(1+\tau)\right] \qquad a \in (0, a_E).$$

In equilibrium, in the event an industry is in state A_+, the quality leader charges the price $p = p^*$ in both markets but earns larger profits in the Home market due to the absence of trade costs. Moreover, if the local and the exporting leaders of an industry are different firms (state A_-), then $p = p^*$ still holds and relative prices are constant and unaffected by changes in trade costs, because mark-ups depend exclusively on the marginal cost of the competitive fringe of followers. The transmission channel of the Stolper-Samuelson mechanism is through changes in relative prices. So, any effect a reduction in trade costs might have on the skill premium w_H/w_L must go through other channels.

2.6. Innovation Incentives. Let $\nu \equiv \nu(a, \omega, t)$ denote the expected discounted profits associated with profits in the Home market and $\nu^* \equiv \nu^*(a, \omega, t)$ the expected discounted profits associated with profits in the Foreign market. Assume you are a local leader; then if a Home or a Foreign follower discovers the next high-quality product and also manages to export it, that is, with instantaneous probability $[I + I^*] G(a_E)$, your losses are equal to ν. The losses are also ν if a Home follower discovers the next higher-quality product but does not manage to export it (with probability $[I][G(a_L) - G(a_E)]$). The shareholder of a stock issued by this firm receives a dividend $\pi(a, \omega, t)$, and the value of the firm appreciates by $\dot{\nu}$ during an infinitesimal time interval. Efficiency in the stock market requires that the expected rate of return of a stock issued by a successful R&D firm must be equal to the riskless rate of return r:

$$r\nu = \pi + \dot{\nu} - \nu [I + I^*] G(a_E) - \nu [I][G(a_L) - G(a_E)].$$

Solving for v, I get an asset equation associated with leadership in the local/Home market,

$$\nu = \frac{\pi}{r - \frac{\dot{\nu}}{\nu} + I[G(a_L) + G(a_E)]}. \tag{2.21}$$

Similar reasoning leads me to an asset equation associated with leadership in the Foreign market

$$\nu^* = \frac{\pi^*}{r - \frac{\dot{\nu}^*}{\nu^*} + I[G(a_L) + G(a_E)]}. \tag{2.22}$$

In these two last equations, profit flows are discounted using the riskless rate of return and the instantaneous probability of being driven out of business by further innovation $I\left[G(a_L)+G(a_E)\right]$; that is, the Schumpeterian creative-destruction effect.

Notice however that the ex ante value of a successful innovation has to consider the sunk costs associated with it. For selling in the domestic market X_tF_L units of skilled labor are required at a cost of $w_HX_tF_L$ and exporting requires X_tF_E units of skilled labor at a cost of $w_HX_tF_E$. The ex-ante expected value $V(\omega,t)$ of innovating is therefore

$$V(\omega,t)=\int_0^{a_L}\left\{\nu(a)-w_HX_tF_L\right\}dG(a)+\int_0^{a_E}\left\{\nu^*(a)-w_HX_tF_E\right\}dG(a). \tag{2.23}$$

I assume that there is free entry into R&D races. Free entry implies that the ex-ante expected return from developing a blueprint V must be equal to the expected costs of innovating $F_Rw_HX_t$, implying that

$$S(\omega,t)\equiv\frac{V(\omega,t)}{F_RX_t}=w_H. \tag{2.24}$$

The ratio $\frac{V(\omega,t)}{F_RX_t}\equiv S(\omega,t)$ can be thought as the "relative reward for innovating" since it measures the reward for innovating relative to its difficulty. $S(\omega,t)$ will be constant in steady-state because the reward for innovating $V(\omega,t)$ increases over time given that the size of the economies grow, but X_t increases as well as new quality improvements become more difficult to discover. The following lemma establishes a relation between this relative reward for innovating and factor prices.

Lemma 1. *(A Schumpeterian version of the Stolper Samuelson mechanism): An increase in the relative reward of innovating $S(\omega,t)$,*

i) raises the wage of skilled workers relative to the wage of unskilled workers w_H/w_L, and

ii) decreases the fraction of the population that decides to remain unskilled θ_0.

Proof: i) follows from equation (2.24) and the fact that the wage of unskilled workers was normalized to 1; and ii) follows from the training condition (2.7).

Conditions (2.23) and (2.24) indicate that the ex-ante expected return from a quality improvement is equal to the sum of expected discounted profits (net of sunk costs for implementation in local and export markets) associated with a draw a from selling in the local and export markets. If I combine these conditions with equations (2.21) and (2.22), I obtain

$$\int_0^{a_L}\left\{\frac{\pi\left(a\right)}{r\left(t\right)+\left[I\right]\left[G(a_L)+G(a_E)\right]-\left(\frac{\dot{X}_t}{X_t}\right)}-w_HX_tF_L\right\}dG(a)+$$
$$+\int_0^{a_E}\left\{\frac{\pi^*\left(a\right)}{r\left(t\right)+\left[I\right]\left[G(a_L)+G(a_E)\right]-\left(\frac{\dot{X}_t}{X_t}\right)}-w_HX_tF_E\right\}dG(a)$$
$$= F_Rw_HX_t.$$

Since only firms with $a < a_L$ produce, I can divide everything by $G(a_L)$ and get the truncated distribution $G\left(a\right)/G(a_L)$. If I then substitute for the profit equations (2.17) and (2.19) into this expression, I get an innovation incentives equation of the economy,

$$\frac{N_tc}{r+I\left[G(a_L)+G(a_E)\right]-\left(\frac{\dot{X}_t}{X_t}\right)}\Delta = w_HX_t\bar{F} \tag{2.25}$$

where

$$\Delta \equiv \int_0^{a_L}\left[1-\frac{a+f}{f\lambda}\right]\frac{g(a)da}{G(a_L)}+\int_0^{a_E}\left[1-\frac{\tau\left(a+f\right)}{f\lambda}\right]\frac{g(a)da}{G(a_L)} \tag{2.26}$$

and

$$\bar{F}\equiv\frac{F_R}{G(a_L)}+F_L+F_E\frac{G(a_E)}{G(a_L)}. \tag{2.27}$$

The first term of the RHS of (2.25), $w_HX_tF_R\frac{1}{G(a_L)}$ is the expected sunk cost associated with developing a new variety and $\frac{1}{G(a_L)}=\left(\frac{\bar{a}}{a_L}\right)^k$, can be interpreted as the number of successful arrivals needed before one of those arrivals is cost-effective enough to be produced in the local market. $w_HX_tF_L$ is the sunk cost of local market adaptation paid by all producing firms. The term $w_HX_tF_E\frac{G(a_E)}{G(a_L)}$ is the expected sunk cost associated with adapting a variety to the foreign market where $\frac{G(a_E)}{G(a_L)}=\left(\frac{a_E}{a_L}\right)^k$ represents the likelihood of developing a variety profitable enough to export, given that local market entry has taken place.$w_HX_t\bar{F}$ therefore represents the ex-ante expected sunk cost of developing a profitable variety at time t.

2.7. Local and Foreign Market Entry Conditions. Firms with threshold values a_L and a_E are indifferent between entering and not entering the local and foreign markets respectively and in equilibrium the benefits of entering must be balanced by the costs of entering:

$$v_L\equiv\nu\left(a_L,\omega,t\right)=w_HX_tF_L \tag{2.28}$$

$$v_E \equiv \nu^*\left(a_E, \omega, t\right) = w_H X_t F_E. \tag{2.29}$$

This implies that $\frac{\dot{\nu}_i}{\nu_i} = \frac{\dot{X}_t}{X_t} = r + I\left[G(a_L) + G(a_E)\right] - \frac{\pi(a_i)}{\nu_i}$, $i \in \{L, E\}$; where the last equality follows from equations (2.21) and (2.22). These equations can therefore be rewritten as

$$v_L = \frac{\pi\left(a_L\right)}{r + I\left[G(a_L) + G(a_E)\right] - \left(\frac{\dot{X}_t}{X_t}\right)}$$

$$\nu_E = \frac{\pi\left(a_E\right)}{r + I\left[G(a_L) + G(a_E)\right] - \left(\frac{\dot{X}_t}{X_t}\right)}.$$

These results can be combined with the profit expressions (2.17) and (2.19) and the cut-off conditions (2.28) and (2.29) to get a local market entry condition:

$$\frac{\frac{N_t c}{f\lambda}\left[f\lambda - (a_L + f)\right]}{r + I\left[G(a_L) + G(a_E)\right] - \left(\frac{\dot{X}_t}{X_t}\right)} = w_H X_t F_L \tag{2.30}$$

and a foreign market entry condition:

$$\frac{\frac{N_t c}{f\lambda}\left[f\lambda - \tau\left(a_E + f\right)\right]}{r + I\left[G(a_L) + G(a_E)\right] - \left(\frac{\dot{X}_t}{X_t}\right)} = w_H X_t F_E. \tag{2.31}$$

The ratio of (2.30) to (2.31) is

$$\frac{f\lambda - (a_L + f)}{f\lambda - \tau\left(a_E + f\right)} = \frac{F_L}{F_E}. \tag{2.32}$$

Equation (2.32) defines the combination of the threshold values a_L and a_E that satisfy cut-off conditions (2.28) and (2.29). The intuition for a_L and a_E being positively related is that in a steady-state equilibrium, the relative profitability of the threshold firms with marginal costs a_L and a_E has to be constant, that is, the ratio v_L/v_E, has to be constant. If a_L increases, the market value v_L falls (it becomes relatively easier to enter the local market). For v_L/v_E, to be constant; the market value v_E has to decrease as well (it becomes relatively easier to export an innovation), which requires a higher a_E.

2.8. Labor Markets. Manufacturing activities use unskilled workers only, whose use is in these activities exclusively. Furthermore, all unskilled-labor demand comes from leading firms, since these are the only ones that produce in equilibrium. Because of the symmetric country assumption, I will concentrate on the labor market equilibrium for the Home country.

In A_+ industries, τQ^* is what the leader produces at Home to sell Q^* in the foreign market and Q is what the leader produces and sells at Home. Given that half of all

A_+ industries have a Home leader, Home´s output in A_+ industries can be expressed as

$$N_{A_+}\frac{\tau Q^* + Q}{2}.$$

In a leading firm, $a+f$ units of unskilled labor are required per unit of output produced. Given that the average demand for unskilled labor will in this case be conditional on $a \in (0, a_E)$, Home´s total unskilled labor demand in A_+ industries is then

$$N_{A_+}\frac{\int_0^{a_E}(a+f)\,\tau Q^* \frac{dG(a)}{G(a_E)} + \int_0^{a_E}(a+f)\,Q\frac{dG(a)}{G(a_E)}}{2}. \tag{2.33}$$

In an A_- industry, there are two distinct producers: the local leader at Home (with the highest quality but not sufficiently cost-effective to export) and the exporting leader. The local leader sells Q to Home consumers and has unit costs $a+f$, $a \in (a_E, a_L)$. The exporting leader, sells a lower quality product but it is still the highest quality available for Foreign consumers, meaning that he can still apply limit pricing and be the only producer for the foreign market. He exports τQ^* in order to sell Q^*, with unit costs of production $a+f$, $a \in (0, a_E)$. Home´s total unskilled labor demand in A_- industries is then

$$N_{A_-}\frac{\int_0^{a_E}(a+f)\,\tau Q^* \frac{dG(a)}{G(a_E)} + \int_{a_E}^{a_L}(a+f)\,Q\frac{dG(a)}{G(a_L)-G(a_E)}}{2}. \tag{2.34}$$

In industries where there is no trade (B-type industries), each country has a local leader that produces output Q. Because a non-exporting firm has a unit labor requirement based on $a \in (a_E, a_L)$, Home´s unskilled labor demand in B industries is

$$N_B\int_{a_E}^{a_L}(a+f)\,Q\frac{dG(a)}{G(a_L)-G(a_E)}. \tag{2.35}$$

Using equations (2.18) and (2.20), Home´s total demand for unskilled labor in manufacturing is therefore equal to

$$\frac{cN_t}{2f\lambda}\left\{\begin{array}{l} N_{A_+}\int_0^{a_E}(a+f)(\tau+1)\frac{dG(a)}{G(a_E)} \\ +N_{A_-}\left[\int_0^{a_E}(a+f)\,\tau\frac{dG(a)}{G(a_E)} + \int_{a_E}^{a_L}(a+f)\frac{dG(a)}{G(a_L)-G(a_E)}\right] \\ +N_B 2\int_{a_E}^{a_L}(a+f)\frac{dG(a)}{G(a_L)-G(a_E)}. \end{array}\right\} = \theta_0 N_t = L_t,$$

where the right-hand-side is total supply given by equation (2.8). Divide both sides by N_t to obtain a Home (or Foreign) per capita version of the full employment condition for unskilled labor

$$\frac{q_t}{N_t} = \theta_0, \tag{2.36}$$

where $\frac{q_t}{N_t} \equiv \frac{c\gamma}{2f\lambda}$ is the per capita final output produced and

$$\gamma \equiv \left\{ \begin{array}{l} N_{A_+} \int_0^{a_E} (a+f)(\tau+1) \frac{dG(a)}{G(a_E)} \\ +N_{A_-} \left[\int_0^{a_E} (a+f)\, \tau \frac{dG(a)}{G(a_E)} + \int_{a_E}^{a_L} (a+f) \frac{dG(a)}{G(a_L)-G(a_E)} \right] \\ +N_B 2 \int_{a_E}^{a_L} (a+f) \frac{dG(a)}{G(a_L)-G(a_E)} \end{array} \right\}.$$

Moving to the skilled labor intensive sectors, skilled labor is used for three purposes: R&D, local market implementation activities and foreign market implementation activities. The industry demand for skilled labor in R&D is $F_R I X_t$. Furthermore, since the measure of industries is one and Home does R&D in all of them, its country-wide demand in R&D is also $F_R I X_t$. Successful firms incur sunk costs for local and export production. During a time interval $dt, G(a_L) I dt$ industries implement their innovations in the local market. Since $X_t F_L$ units of skilled labor are required for local market implementation activities, total demand for skilled workers used in those activities at Home is $I X_t F_L G(a_L)$. Similarly, the demand for skilled workers used in foreign market implementation activities is $I X_t F_E G(a_E)$. Adding these terms up yields the demand for skilled labor in the economy. Combining with the supply of skilled labor given by equation (2.9) and dividing by N_t, I get the per capita supply-demand condition for skilled labor:

$$\left(\frac{\theta_0 + 1 - 2\sigma}{2}\right)(1-\theta_0)\, e^{-nT} = F_R I \varkappa + F_L G(a_L) I \varkappa + F_E G(a_E) I \varkappa, \qquad (2.37)$$

where $\varkappa \equiv X_t/N_t$. This completes the description of the model.

3. Steady State Equilibrium

I solve the model for a steady-state equilibrium where per capita consumption c, relative R&D difficulty $\varkappa$, the relative reward for innovating S, innovation rates $I = I^*$ and factor wages w_H and w_L are all constant over time and across industries $\omega \in [0,1]$.

If factor prices are constant, it follows from equation (2.7), that θ_0 is constant as well. From the Euler equation (2.5), I have that the market risk-free interest rate is constant and equal to $r_t = \rho$.

Using the fact that in a steady state equilibrium, returns in all markets must grow at the same rate, $\frac{\dot{\nu}^*}{\nu^*} = \frac{\dot{\nu}}{\nu}$, equations (2.17)-(2.19) and (2.21)-(2.22) can be used to get

$$\frac{\dot{\nu}^*}{\nu^*} = \frac{\dot{\nu}}{\nu} = \frac{\dot{\pi}}{\pi} = \frac{\dot{\pi}^*}{\pi^*} = \frac{\dot{\Pi}}{\Pi} = \frac{\dot{L}}{L} = n.$$

From the "relative reward for innovating" equation (2.24), and the fact that S and $\varkappa \equiv X_t/N_t$ also must be constant in steady-state, it follows that

$$\frac{\dot{V}}{V} = \frac{\dot{X}(\omega,t)}{X(\omega,t)} = n.$$

Combining this result with equation (2.11), I get the steady-state value of the innovation rate:

$$I(\omega,t) = \frac{n}{\mu 2}. \tag{3.1}$$

In order to obtain a steady-state expression for the per capita consumption level c, I can use equations (2.25) and (3.1), obtaining

$$c = w_H \varkappa \frac{\bar{F}\left[\rho - n + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right]\right]}{\Delta}, \tag{3.2}$$

which combined with the per capita final output produced q_t/N_t and equation (2.7) yields

$$q_t(\theta_0 - \sigma) = e^{\rho T} N_t \left\{\rho - n + \frac{n}{\mu 2}\left[G(a_E) + G(a_L)\right]\right\} \varkappa \Psi$$

where $\Psi \equiv \frac{\bar{F}\gamma}{2f\lambda\Delta}$. Substituting into equation (2.36), I obtain a steady-state "unskilled-labor condition"[22]

$$\theta_0(\theta_0 - \sigma) = e^{\rho T}\left\{\rho - n + \frac{n}{\mu 2}\left[G(a_E) + G(a_L)\right]\right\} \varkappa \Psi. \tag{3.3}$$

For the skilled workers, I use equations (2.37) and (3.1) to obtain a steady-state "skilled-labor condition"

$$\left(\frac{\theta_0 + 1 - 2\sigma}{2}\right)(1 - \theta_0) e^{-nT} = \frac{n}{\mu 2} \varkappa \left[F_R + F_E G(a_E) + F_L G(a_L)\right]. \tag{3.4}$$

Equations (3.3) and (3.4) determine a system of two equations and two unknowns: θ_0 and $\varkappa$, once a_E and a_L have been determined.

For obtaining expressions for variables a_E and a_L I use equation (2.32) that in steady-state defines all combinations of a_L and a_E where the local and foreign markets entry conditions (2.30) and (2.31) hold. Equation (2.32) can therefore be rewritten in reduced form as:

$$a_L = a_L(a_E) \text{ or } a_E = a_E(a_L). \tag{3.5}$$

[22] See Appendix B for details.

I use the local market entry condition (2.30) to solve for F_L. By combining this result with equation (2.25) and the steady-state conditions $\frac{\dot{X}(\omega,t)}{X(\omega,t)} = n$, $r = \rho$ and $I = \frac{n}{\mu 2}$, I obtain

$$D_L(a_L) \equiv \int_0^{a_L} F_L \left\{ \frac{[f\lambda - (a+f)]}{[f\lambda - (a_L+f)]} - 1 \right\} dG(a) + \int_0^{a_E(a_L)} \left\{ F_L \frac{[f\lambda - \tau(a+f)]}{[f\lambda - (a_L+f)]} - F_E \right\} dG(a) = F_R. \tag{3.6}$$

$D_L(.)$ is increasing in a_L because a higher a_L makes products more likely to be implemented in the local market. It is an upward sloping curve in (a_L, D_L) space and its intersection with the horizontal line F_R determines the steady-state value of a_L.[23]

Likewise, I can solve for F_E using equation (2.31) and substitute the result into (2.25) to obtain

$$D_E(a_E) \equiv \int_0^{a_L(a_E)} \left\{ F_E \frac{[f\lambda - (a+f)]}{[f\lambda - \tau(a_E+f)]} - F_L \right\} dG(a) + \int_0^{a_E} F_E \left\{ \frac{[f\lambda - \tau(a+f)]}{[f\lambda - \tau(a_E+f)]} - 1 \right\} dG(a) = F_R. \tag{3.7}$$

$D_E(.)$ is increasing in a_E because a higher a_E makes products more likely to be exported, increasing the expected value of an innovation. It is an upward sloping curve in (a_E, D_E) space and its intersection with the horizontal line F_R determines the steady-state value of a_E.[24]

In this model, trade liberalization can be identified with a decrease in τ or a decrease in F_E. Given our results expressed in (3.6) and (3.7), I obtain the following theorem:

THEOREM 3. *A decrease in the trade cost τ or the beachhead cost F_E decreases the value of a_L and increases the value of a_E and hence narrowing the gap between them. A fall in a_L causes the least productive firms to exit. An increase in a_E causes the most productive locally producing firms to become exporters.*

The proof follows directly from (3.6) and (3.7).[25] A lower a_L makes it more difficult to produce locally and causes the least productive firms to shut down production. But a higher a_E makes it relatively easier to export and provides new higher-quality products easier access to the foreign market. These now-exporting producers, given their production costs, were not able to export when trade costs were higher.

Given that changes in τ or in the sunk cost for exporting F_E affect the threshold values a_L and a_E, there is also a reallocation of industry types across the economies:

23 See Appendix B for details.
24 See Appendix B for details.
25 See Appendix B for a detailed proof.

LEMMA 2. *A decrease in the trade cost τ or the beachhead cost F_E,*

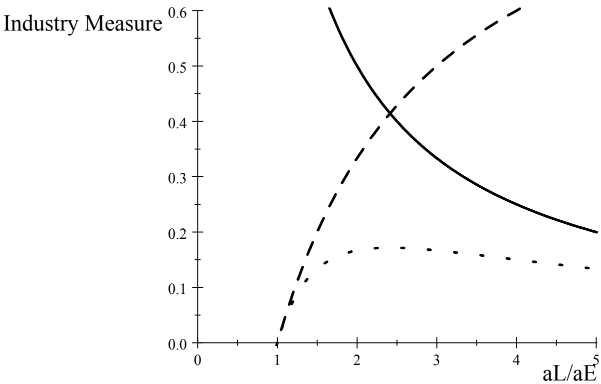
i) increases the number of industries exporting the state of the art product (the A_+ industries),

ii) decreases the number of industries that do not trade (the B industries)

iii) has an ambiguous effect on the number of A_--type industries.

Proof: Follows from Theorem 1 and equations (2.13), (2.14) and (2.15).[26]

The higher-quality extensive margin (the number of industries that export higher-quality goods) increases univocally when τ falls increasing the shares of high- relative to low-quality goods in export and import bundles. The following graph describes how industry types change due to changes in the a_L to a_E ratio



N_{A_+} in solid, N_{A_-} in dots, N_B in dash

Next, I determine the effects a decrease in τ has on θ_0 and $\varkappa$.

I will first establish the impact θ_0 has on relative wages. For that purpose, I can rewrite the unskilled and skilled labor conditions (equations (3.3) and (3.4)) as

$$\varkappa = \frac{\theta_0 \left(\theta_0 - \sigma\right)}{e^{\rho T} \left\{ \rho - n + \frac{n}{\mu 2} \left[G(a_E) + G(a_L)\right] \right\} \Psi} \tag{3.8}$$

and

$$\varkappa = \frac{\left(\theta_0 + 1 - 2\sigma\right)\left(1 - \theta_0\right) \frac{e^{-nT}}{2}}{\frac{n}{\mu 2}\left[F_R + F_E G\left(a_E\right) + F_L G\left(a_L\right)\right]}. \tag{3.9}$$

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[26] See Appendix B for details.

These two equations can be represented in $(\varkappa, \theta_0)$ space where the steady-state unskilled-labor condition (3.8) is an upward sloping curve and where the steady-state skilled-labor condition (3.9) is a downward sloping curve[27]. There exists an intersection since $\theta_0 = 1$ if $\varkappa = 0$ in the skilled labor condition; $\theta_0 = \sigma$ if $\varkappa = 0$ and $\lim_{\varkappa \to \infty} \theta_0 = \infty$ in the unskilled labor condition. The system is one of two equations and two unknowns $(\varkappa, \theta_0)$. These equations are illustrated in Figure 1 and are labeled "Unskilled" and "Skilled", respectively.

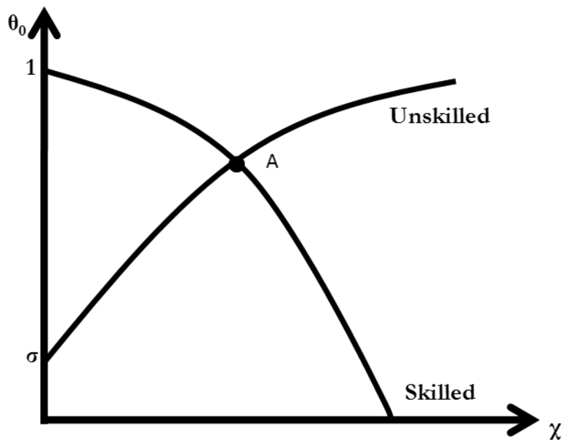

Figure 1

The main question of the paper is to analyze the consequences of trade liberalization $(\tau \downarrow)$ on relative R&D difficulty $(\varkappa)$ and on the threshold value that determines whether an individual will become a skilled worker or not (θ_0). Comparative statics of the system (3.8)-(3.9) are analytically untractable, so I simulate the model and solve it numerically.

In the computer simulations, I have used the following benchmark parameter values: $\rho = 0.03$, $n = 0.01$, $\lambda = 1.35$, $\mu = 0.15$, $\sigma = 0.6$, $f = 4$ and $T = 4$. The common subjective discount rate ρ was chosen to generate a 3-percent steady-state real interest rate. The population growth rate n is 1 percent and each innovation represents a 35-percent improvement in product quality. The R&D difficulty parameter μ was

[27] See Appendix B for details.

chosen to generate a 2-percent steady-state growth rate[28]. The dispersion parameter σ guarantees that no more than 40 percent of the labor force becomes skilled and generates a reasonable level of dispersion in the wages of skilled workers. $T = 4$ corresponds to a four year training period. These parameters are similar to those used in Dinopoulos and Segerstrom (1999) with the exception of those parameters absent in their model: the marginal cost of followers $f = 4$, $\bar{a} = 2$ and $k = 2.9$ in order to guarantee positive profits in both markets. The sunk costs for implementing locally and in the foreign market were set to $F_L = 4$ and $F_E = 5$. The sunk cost for innovating was set to $F_R = 1$. The results are robust to a wide range of parameter values as long as the nonnegative profit condition holds. For constructing the benchmark case, for the trade barrier τ I use the arithmetic average protection rate in industrial goods in the EU (7.7 percent) as reported by Messerlin (2001). I consider this figure realistic given that the major tariff differences between the EU and the US are in the agricultural sector, not in the industrial sector. Other authors such as Anderson and Van Wincoop (2003) consider this value appropriate for measuring US-Canada trade costs as well.[29] In the benchmark case, the model predicts that 25 percent of all firms export. This is roughly consistent with the data from the 1992 U.S. Census of Manufacturers where 21 percent of the interviewed firms report exporting. In the model, skilled workers can be interpreted as scientists and engineers working in R&D activities and unskilled workers can be interpreted as production workers. For determining their relative size in the benchmark case, I use the share of R&D employment to domestic employment in R&D performing companies, which is approximately 3 percent (implying $\theta_0 = .97$ in the model) for the period 1970-1999 according to the National Science Foundation (NSF).[30] In equilibrium, the highest paid R&D workers earn roughly 3 times more than the lowest paid skilled workers. For example, according to the NSF, the median annual salaries of full time employed doctoral scientists and engineers was 85,900 dollars for all fields in 2006. The median annual salaries of U.S. scientists and engineers in business and industry was 65,000 dollars for all degree levels and 72,000 for a master´s degree in 1999. For production occupations, the Bureau of Labor Statistics (BLS) reports a mean annual wage estimate of 30,480 dollars for 2006 while it was 25,400 dollars in 1999.

[28] From Appendix A, we have that $g \equiv \frac{\dot{u}_\theta}{u_\theta} = .02 = \frac{n}{\mu} \ln \lambda = \frac{.01}{.15} \ln 1.35$.

[29] Hummels (2003) for instance, measures transport costs and freight rates for the US and indicates that across commodities, for the U.S., the range of trade weighted averages goes from less than 1 percent (transport equipment) to 27 percent (fertilizers) and the arithmetic averages range from 5,7 percent for machinery to 15,7 percent for mineral fuels.

[30] The ratio of total R&D employment to total employment is less than 1 percent according to the NSF. Given that all firms perform R&D in the model, I consider the other measure more accurate.

Table 2 shows the net effects different trade costs have on $\varkappa$, θ_0 and on other variables of the model. Table 3 shows the same exercise for $F_L = F_E = 4$.

$\boldsymbol{\tau}$	*1.18*	*1.13*	*1.10*	**1.077**	*1.03*	*1.025*	*1.00*
$\mathbf{w}_H/\mathbf{w}_L$	3.006	3.012	3.021	**3.031**	3.068	3.073	3.104
$\boldsymbol{\theta}_0$	0.975	0.974	0.973	**0.972**	0.968	0.967	0.963
$\varkappa$	0.150	0.151	0.152	**0.154**	0.164	0.165	0.173
$\mathbf{a}_E$	0.354	0.504	0.619	**0.707**	0.887	0.906	0.998
$\mathbf{a}_L$	1.156	1.151	1.144	**1.136**	1.107	1.103	1.079
N_{A+}	0.032	0.091	0.168	**0.253**	0.526	0.565	0.799
N_B	0.937	0.833	0.712	**0.596**	0.310	0.278	0.112
N_{A-}	0.031	0.076	0.120	**0.151**	0.164	0.157	0.089

Table 2

$\boldsymbol{\tau}$	*1.18*	*1.13*	*1.10*	**1.077**	*1.03*	*1.025*	*1.00*
$\mathbf{w}_H/\mathbf{w}_L$	3.006	3.012	3.022	**3.033**	3.070	3.076	3.110
$\boldsymbol{\theta}_0$	0.975	0.974	0.973	**0.972**	0.967	0.966	0.963
$\varkappa$	0.150	0.151	0.153	**0.157**	0.169	0.171	0.181
$\mathbf{a}_E$	0.405	0.556	0.672	**0.762**	0.944	0.963	1.058
$\mathbf{a}_L$	1.154	1.148	1.139	**1.128**	1.093	1.087	1.058
N_{A+}	0.048	0.122	0.216	**0.320**	0.655	0.704	1.000
N_B	0.908	0.782	0.644	**0.515**	0.208	0.174	0.000
N_{A-}	0.044	0.095	0.139	**0.165**	0.136	0.122	0.000

Table 3 ($F_L = F_E$)

These simulations show that a decrease in τ causes the relative R&D difficulty $\varkappa$ to increase and the educational threshold value θ_0 to decrease. This is equivalent to a shift to the right of the Unskilled curve and a shift to the right of the Skilled curve in Figure 1. The net effect, however, is a higher value of $\varkappa$ and a lower value of θ_0. Figure 2 indicates how the curves in Figure 1 shift and the new intersection at point

B corresponds to the new steady-state equilibrium with a lower θ_0 and a higher $\varkappa$.

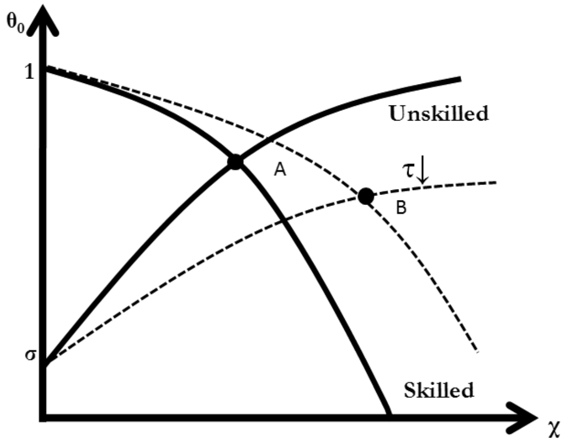

Figure 2

These results are summarized in the following conclusion that is also the main result of the paper:

CONCLUSION 1. *Trade liberalization caused by a permanent reduction in the trade cost* $(\tau\downarrow)$,

i) permanently increases the wage of skilled workers relative to the wage of unskilled workers $(w_H/w_L\uparrow)$,

ii) permanently increases the fraction of skilled workers in the economy by inducing more household members to educate themselves $(\theta_0\downarrow)$, *and*

iii) temporarily increases the rate of technological change $(\chi\uparrow)$.

Theorem 1 stated that trade liberalization made it relatively easier to export $(a_E\uparrow)$. Given that a higher a_E increases the probability a successful innovator has to become the new quality leader in both markets, it increases the profitability of innovating. Under the assumptions that R&D and foreign market implementation activities are skilled-labor intensive, a fall in the iceberg trade cost will raise the demand (and wages) of those workers relative to the unskilled ones. The new skilled wage rate will therefore be higher than the prevailing before trade costs fell. That will increase the supply of skilled labor. That the demand increases follows from equation (2.24): a higher reward for innovating S raises immediately R&D services IX_t.

The model shows that trade liberalization does not have any long-run effects on the rate of technological change. In steady-state the growth rate of $\varkappa$ is equal to $\mu [I + I^*] - n$. So an increase in $\varkappa$ must be associated with a temporary increase of $I + I^*$, that is, the rate of technological change. I have shown in equation (3.1) that this rate depends only on parameters of the model, so the effects trade liberalization has on the rate of technological change is positive, although only temporary[31].

The last exercise of this paper is to analyze the impact trade liberalization has on relative wages when the sunk costs for producing locally F_L or exporting F_E vary. This question can be answered by inspecting equations (2.23) and (2.24), that described the ex-ante expected value of an innovation V_t, and the relative reward for innovating S. From the first equation, it follows that V_t decreases if sunk costs increase ($F_L \uparrow, F_E \uparrow$). A lower V_t in turn implies that $S \equiv \frac{V_t}{X_t} = w_H$ decreases. To sum up, higher sunk costs for implementing innovations reduce the demand for skilled workers in R&D and implementation. Notice also that trade liberalization puts upward pressure on the wages of skilled workers by increasing the ex-ante value of a successful R&D effort V_t. But X_t also increases if τ falls and higher X_t implies higher sunk costs. This reduces the overall impact τ has on V_t and consequently on relative wages, innovation and the rate of technological change. This mechanism or, "sunk-cost channel", suggests that even though the incentives for doing skilled-labor intensive R&D increase when trade is liberalized; the increase in sunk costs for implementing innovations in different markets operates in the other direction, reducing the ex-ante value of a successful discovery. It is therefore "anti-growth" and its effect is larger the higher the sunk costs for implementing innovations are. This sunk-cost channel explains why our results are so modest compared to those found by Dinopoulos and Segerstrom (1999) in their simulations, suggesting that they might have overestimated the role of trade in increasing the skilled-wage premium. The simulations presented in Table 3, where $F_L = F_E$ and similar results on wage inequality, confirm that these differences hinge on the presence of sunk costs and not on the fact that $F_L < F_E$.

4. Conclusions

Trade has not been in the last decade the most accepted transmission channel for analyzing wage dispersion, given that domestic relative prices have not declined (i.e., Lawrence and Slaughter, 1993). The new-new trade literature has put focus

[31] That long-run growth rates are independent of any policy variable is a common property of all semi-endogenous growth models. This property is consistent with the evidence presented in Jones (1995a), in particular for the U.S. The main results of the model (θ_0 falls and $\varkappa$ increases when τ falls) with the addition of permanent effects on growth could easily be obtained by changing the specification of equation (2.11).

on intra-industry firm heterogeneity, successfully accounting for many new firm-level empirical facts[32]. Those models, however, have typically worked within the variety expansion approach and with one factor only; being unable to address questions on wage inequality. Models with more than one factor use Heckscher-Ohlin-Samuelson or Ricardian frameworks and have not managed to keep domestic prices constant when trade costs fall.

In this paper, I construct a quality-ladders endogenous growth model with trade and intra-industry firm heterogeneity that tries to fill that void. This framework suggests that some of the observed wage dispersion might have been caused by trade liberalization, challenging the idea that the worsening conditions of the less skilled workers is exclusively domestic driven by unskilled-labor saving technological change, by competition from unskilled abundant countries or by nonmarket factors such as lower minimum wages or weak labor unions.

The link between wages and trade liberalization in this model goes through prices, although not the prices of final goods, but through other channel; namely the relative price of innovation. A fall in the level of trade costs increases the reward for innovating. The implied increase in profitability in R&D activities generates long-run reallocations of resources into that sector and increases permanently the wage of those used intensively in R&D activities, namely skilled workers.

The quantitative results of the model however, suggest that this trade channel mechanism, present in similar models with trade and Schumpeterian growth (i.e. Dinopoulos and Segerstrom, 1999; Segerstrom, 2009), might have overestimated the role of trade. This is so because in those models, skilled workers are only used intensively in R&D and there are no costs associated with implementing innovations. In this paper, skilled workers are also intensively used in implementing products for different markets, which constitute a sunk cost for the firm. There is therefore an additional force, a sunk-cost channel, working in the opposite direction when trade is liberalized. The presence of sunk costs for producing, increase the costs for implementing the state-of-the-art quality, which reduces the ex-ante value of an innovation, deterring firms from doing R&D, even though trade costs fall. The increase in relative demand for skilled workers as a consequence of trade liberalization is therefore lower compared to the case when skilled labor is used intensively in R&D only.

The model´s results are robust to several specifications and several versions of this model have been built (with international spillovers, ad-valorem tariffs and Cournot competition with a producing competitive fringe). They all deliver similar results. These versions have the drawback that they add unnecessary complexity. A setting

[32] See Tybout (2003) for a survey.

with asymmetric countries is a path for future research although the main challenge in such a scenario would be to disentangle the Heckscher-Ohlin-Samuelson mechanism from the Schumpeterian mechanism, here described.

5. Appendix A

In this Appendix, household optimization calculations are spelled out in more detail. In what follows, I omit the subscript θ for notational simplicity.

5.1. Consumer Optimization. The first step is to solve for the allocation of consumer expenditure across products within a particular industry ω at time t. Since all products in an industry are perfect substitutes by assumption (equation 2.2) and only differ in their quality, consumers only buy the product(s) with the lowest quality adjusted price $\frac{p(j,\omega,t)}{\lambda^j}$. The easiest way to see this is to solve the simple consumer optimization problem $\max_{q_1,q_2} q_1+\lambda q_2$ subject to $p_1q_1 + p_2q_2 = c$, $q_1 \geq 0$ and $q_2 \geq 0$. The solution is to only buy good 1 if $p_1 < \frac{p_2}{\lambda}$ and only buy good 2 if $p_1 > \frac{p_2}{\lambda}$.

The second step is to solve for the allocation of individual consumer expenditure $c(t)$ across industries at time t. For the set of products with the lowest quality-adjusted price in industry ω at time t, let $p(\omega, t)$ denote the price of the highest quality product and let $q(\omega, t)$ denote the quality-weighted quantity consumed of products, measured in units of the highest quality product. Then the static problem of allocating consumer expenditure across industries becomes

$$\max_{q_\theta(.)} \int_0^1 \ln\left[\lambda^{j(\omega,t)} q(\omega,t)\right] d\omega$$
$$s.t. \int_0^1 \left[p(\omega,t)\, q(\omega,t)\right] d\omega = c(t),$$

where $j(\omega, t)$ equals the number of innovations in industry ω from time 0 at time t. This problem can be rewritten as the optimal control problem

$$\max_{q_\theta(.)} \int_0^1 \ln\left[\lambda^{j(\omega,t)} q(\omega,t)\right] d\omega$$
$$s.t. \frac{\partial y(\omega,t)}{\partial \omega} = \left[p(\omega,t)\, q(\omega,t)\right], y(0,t) = 0, y(1,t) = c(t),$$

where $y(\omega, t)$ is a new state variable. The Hamiltonian for this optimal control problem is

$$H \equiv \ln\left[\lambda^{j(\omega,t)} q(\omega,t)\right] + \mu(\omega,t)\left[p(\omega,t)\, q(\omega,t)\right]$$

where $\mu(\omega, t)$ is the costate variable. The costate equation

$$-\dot{\mu} = -\frac{\partial \mu(.)}{\partial \omega} = \frac{\partial H}{\partial y} = 0$$

indicates that μ is constant across ω. Taking this into account, Pontryagin´s maximum principle implies that:

$$\begin{aligned}\frac{\partial H}{\partial q(\omega,t)} &= 0 = \frac{\lambda^{j}}{\lambda^{j} q(\omega,t)} + \mu(t)\, p(\omega,t) \\ &\rightarrow q(\omega,t) = \frac{1}{-\mu(t)\, p(\omega,t)}.\end{aligned}$$

Substituting this result into the budget constraint delivers

$$\begin{aligned}c(t) &= \int_0^1 [p(\omega,t)\, q(\omega,t)]\, d\omega \\ &= \int_0^1 \left[p(\omega,t)\frac{1}{-\mu(t)\, p(\omega,t)}\right] d\omega \\ &= \int_0^1 \left[\frac{1}{-\mu(t)}\right] d\omega = \frac{1}{-\mu(t)}\,[\omega]_0^1 \\ &= \frac{1}{-\mu(t)}.\end{aligned}$$

So

$$\begin{aligned}c(t) &= \frac{1}{-\mu(t)} = p(\omega,t)\, q(\omega,t) \\ &\rightarrow q(\omega,t) = \frac{c(t)}{p(\omega,t)},\end{aligned}$$

which is a unit elastic demand function for the product in each industry with the lowest quality adjusted price. Given this result, it follows that equation (2.2) can be rewritten as

$$\ln u(t) = \int_0^1 \ln\left[\lambda^{j(\omega,t)}\frac{c(t)}{p(\omega,t)}\right] d\omega.$$

The third step is to maximize the household´s discounted utility (2.1) subject to its intertemporal budget constraint (2.4). Notice that

$$\begin{aligned}\ln u(t) &= \int_0^1 \ln\left[\lambda^{j(\omega,t)}\frac{c(t)}{p(\omega,t)}\right] d\omega \\ &= \int_0^1 \left[\ln \lambda^{j(\omega,t)} + \ln c(t) - \ln p(\omega,t)\right] d\omega \\ &= \int_0^1 \ln \lambda^{j(\omega,t)} d\omega + \ln c(t) - \int_0^1 \ln p(\omega,t)\, d\omega.\end{aligned}$$

In this model the consumer takes prices and the evolution of innovations as given, so the two integrals can be ignored in solving the household´s dynamic optimization problem. As before, I can redefine the problem in terms of a new state variable y :

$$\begin{aligned}\max_{c(.)} U &\equiv \int_0^\infty N_0 e^{-(\rho-n)t} \ln\left[c(t)\right] dt \\ s.t.\ y(0) &= 0,\ \dot{y}(t) = c(t)\, e^{nt} e^{-R(t)},\ \lim_{t\to\infty} y(t) = W_\theta + Z_\theta.\end{aligned}$$

The Hamiltonian is therefore

$$H \equiv N_0 e^{-(\rho-n)t} \ln\left[c(t)\right] + \mu(t)\left[c(t)\, e^{nt} e^{-R(t)}\right]$$

where $\mu(t)$ is the costate variable. The costate equation is

$$-\dot{\mu} = \frac{\partial \mu}{\partial t} = \frac{\partial H}{\partial y} = 0,$$

meaning that μ is constant over time. Taking this into account, the Pontryagin maximum principle is

$$\frac{\partial H}{\partial c(t)} = N_0 e^{-(\rho-n)t} \frac{1}{c(t)} + \mu e^{nt} e^{-R(t)} = 0$$

or

$$c(t) = \frac{N_0 e^{-(\rho-n)t}}{-\mu e^{[nt-R(t)]}}.$$

Taking logarithms of both sides yields

$$\begin{aligned}\ln c(t) &= \ln N_0 + \ln e^{-(\rho-n)t} - \ln\left[-\mu e^{[nt-R(t)]}\right] \\ &= \ln N_0 - (\rho-n)t - \ln(-\mu) - nt + R(t) \\ &= \ln N_0 - \rho t - \ln(-\mu) + R(t).\end{aligned}$$

Differentiating with respect to time t delivers the standard Euler equation

$$\begin{aligned}\frac{\dot{c}(t)}{c(t)} &= -\rho + \dot{R}(t) \\ &= r(t) - \rho.\end{aligned}$$

The fourth step, making the training/employment decisions that maximize each household's discounted wage income, is described in the main text. Since each household's discounted utility is increasing in consumer expenditure and there is no disutility associated with training or working, each household maximizes its discounted utility by maximizing its discounted wage income.

5.2. Steady State Utility Growth. I can get an expression for the growth rate of consumer utility by substituting the demand function $q(\omega,t)=\frac{c(t)}{f\lambda}$ into the static utility function to get

$$\ln u(t)=\int_0^1 \ln\left[\lambda^{j(\omega,t)}\frac{c(t)}{f\lambda}\right]d\omega=\ln\lambda\int_0^1 j(\omega,t)\,d\omega+\ln c(t)-\ln f\lambda.$$

Recall that $j(\omega,t)$ is the number of quality improvements in industry ω at time t. This number increases over time as new higher quality goods are continuously being introduced. So $\int_0^1 j(\omega,t)\,d\omega$ represents the expected number of quality innovations at the whole-economy level at time t. This is equivalent to the arrival rate of innovations in the economy, namely the Poisson arrival rate $2I$ times t given that $2I$ is constant in steady-state. It follows that

$$\ln u(t)=2It\ln\lambda+\ln c(t)-\ln\lambda.$$

Thus, in the steady-state equilibrium, each consumer's utility grows at the rate

$$\frac{\dot{u}(t)}{u(t)}=\frac{n}{\mu}\ln\lambda$$

given that $\frac{\dot{c}(t)}{c(t)}=0$ and $I=\frac{n}{2\mu}$in steady-state.■

6. Appendix B

6.1. Derivation of Equation (3.3)**.** Per capita final output produced is

$$\frac{q_t}{N_t}\equiv\frac{c\gamma}{2f\lambda}.$$

I can solve for per capita consumption using equation (3.2) :

$$c=w_H\varkappa\frac{\bar{F}\left[\rho-n+\frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]\right]}{\Delta}.$$

Substituting this expression into per capita final output delivers

$$q_t=w_H\varkappa\frac{\bar{F}\left[\rho-n+\frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]\right]N_t\gamma}{\Delta 2f\lambda}.$$

Solving for w_H using equation (2.7) gives $w_H=e^{\rho T}/\left(\theta_0-\sigma\right)$. It follows then that

$$q_t\left(\theta_0-\sigma\right)=e^{\rho T}N_t\left[\rho-n+\frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]\right]\varkappa\Psi$$

where $\Psi\equiv\frac{\bar{F}\gamma}{2f\lambda\Delta}$.■

6.2. Derivation of Equations (3.6) **and** (3.7)**.** I can use the local market entry condition (2.30) to solve for

$$F_L = \frac{N_t c\left[1 - \frac{(a_L+f)}{f\lambda}\right]}{\left[r\left(t\right) + I\left[G(a_L) + G(a_E)\right] - \left(\frac{\dot{X}_t}{X_t}\right)\right] w_H X_t}.$$

By combining this result with equation (2.25) and $\frac{\dot{X}(\omega,t)}{X(\omega,t)} = n$, I get

$$\begin{aligned} & \frac{N_t c}{\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)} \Delta \\ = \;& w_H X_t \left[\frac{F_R}{G(a_L)} + F_L + F_E \frac{G(a_E)}{G(a_L)}\right] \\ = \;& w_H X_t \left[\frac{F_R}{G(a_L)} + \frac{N_t c\left[1 - \frac{(a_L+f)}{f\lambda}\right]}{\left[\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right] w_H X_t} + F_E \frac{G(a_E)}{G(a_L)}\right]; \end{aligned}$$

then

$$\begin{aligned} & \frac{N_t c}{\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)} \left[\Delta - \left[1 - \frac{(a_L+f)}{f\lambda}\right]\right] \\ = \;& w_H X_t \left[\frac{F_R}{G(a_L)} + F_E \frac{G(a_E)}{G(a_L)}\right]. \end{aligned}$$

Recall from (2.26) that $\Delta \equiv \int_0^{a_L} \left[1 - \frac{a+f}{f\lambda}\right] \frac{g(a)da}{G(a_L)} + \int_0^{a_E} \left[1 - \frac{\tau(a+f)}{f\lambda}\right] \frac{g(a)da}{G(a_L)}$; thus

$$\begin{aligned} & \frac{N_t c}{\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)} \left[\begin{array}{c} \int_0^{a_L} \left[1 - \frac{a+f}{f\lambda}\right] \frac{g(a)da}{G(a_L)} \\ -\left[1 - \frac{(a_L+f)}{f\lambda}\right] \\ + \int_0^{a_E} \left[1 - \frac{\tau(a+f)}{f\lambda}\right] \frac{g(a)da}{G(a_L)} \end{array}\right] \\ = \;& w_H X_t \left[\frac{F_R}{G(a_L)} + F_E \frac{G(a_E)}{G(a_L)}\right]. \end{aligned}$$

Multiply on both sides by $G(a_L)$ and $\frac{f\lambda}{f\lambda}$ to obtain

$$\begin{aligned} & \frac{N_t c}{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)} \left[\begin{array}{c} \int_0^{a_L} \left[f\lambda - (a+f)\right] g(a)da - G(a_L)\left[f\lambda - (a_L+f)\right] \\ + \int_0^{a_E} \left[f\lambda - \tau\left(a+f\right)\right] g(a)da \end{array}\right] \\ = \;& w_H X_t \left[F_R + F_E G(a_E)\right], \end{aligned}$$

and divide by $[f\lambda - (a_L + f)]$,

$$\begin{aligned}
&\frac{N_t c}{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)}\left[\begin{array}{c}\int_0^{a_L}\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]}g(a)da - G(a_L)\\ +\int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}g(a)da\end{array}\right]\\
&= \frac{w_H X_t}{[f\lambda - (a_L + f)]}\left[F_R + F_E G(a_E)\right].
\end{aligned}$$

Then

$$\begin{aligned}
&\left[\begin{array}{c}\int_0^{a_L}\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]}g(a)da - G(a_L)\\ +\int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}g(a)da\end{array}\right]\\
&= \frac{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)}{N_t c}\frac{w_H X_t}{[f\lambda - (a_L + f)]}\left[F_R + F_E G(a_E)\right]
\end{aligned}$$

and

$$\begin{aligned}
&\left[\int_0^{a_L}\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]}g(a)da - G(a_L) + \int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}g(a)da\right]\\
&-\frac{w_H X_t}{[f\lambda - (a_L + f)]}\left[F_E G(a_E)\right]\frac{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)}{N_t c}\\
&= \frac{w_H X_t F_R}{[f\lambda - (a_L + f)]}\frac{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L) + G(a_E)\right] - n\right)}{N_t c} = \frac{F_R}{F_L},
\end{aligned}$$

where the last equality follows from equation (2.30). If I multiply this last equation times F_L, I get

$$F_L\left[\int_0^{a_L}\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]}g(a)da - G(a_L) + \int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}g(a)da\right] - F_E G(a_E) = F_R.$$

Using $a_E = a_E(a_L)$ and the fact $\int_0^{a_L} g(a)da = G(a_L)$ and $\int_0^{a_E} g(a)da = G(a_E)$, I get

$$\begin{aligned}
D_L(a_L) &\equiv \int_0^{a_L}\left\{F_L\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]} - F_L\right\}g(a)da +\\
&\quad \int_0^{a_E(a_L)}\left\{F_L\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]} - F_E\right\}g(a)da\\
&= F_R. \blacksquare
\end{aligned}$$

D_E can also be expressed in terms of a_E in a similar manner. Using the foreign market entry condition (2.31) to solve for $F_E = \frac{\frac{N_t c}{f\lambda}[f\lambda - \tau(a_E+f)]}{\left[\rho + \frac{n}{\mu 2}[G(a_L)+G(a_E)] - n\right] w_H X_t}$ and substituting into equation (2.25) yields:

$$\begin{aligned}
&\frac{N_t c}{\left(\rho + \frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}\Delta \\
= \quad & w_H X_t \left[\frac{F_R}{G(a_L)} + F_L + \frac{N_t c\left[1-\frac{\tau(a_E+f)}{f\lambda}\right]}{\left[\rho + \frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right] w_H X_t}\frac{G(a_E)}{G(a_L)}\right]
\end{aligned}$$

$$\begin{aligned}
&\frac{N_t c}{\left(\rho + \frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}\left[\Delta - \left[1-\frac{\tau\left(a_E+f\right)}{f\lambda}\right]\frac{G(a_E)}{G(a_L)}\right] \\
= \quad & w_H X_t \left[\frac{F_R}{G(a_L)} + F_L\right].
\end{aligned}$$

Recall that $\Delta \equiv \int_0^{a_L}\left[1-\frac{a+f}{f\lambda}\right]\frac{g(a)da}{G(a_L)} + \int_0^{a_E}\left[1-\frac{\tau(a+f)}{f\lambda}\right]\frac{g(a)da}{G(a_L)}$ and multiply on both sides by $G(a_L)$ and $\frac{f\lambda}{f\lambda}$ to obtain

$$\begin{aligned}
&\frac{N_t c}{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}\left[\begin{array}{c} \int_0^{a_L}\left[f\lambda-(a+f)\right]g(a)da \\ +\int_0^{a_E}\left[f\lambda-\tau\left(a+f\right)\right]g(a)da \\ -\left[f\lambda-\tau\left(a_E+f\right)\right]G(a_E)\end{array}\right] \\
= \quad & w_H X_t\left[F_R + G(a_L)F_L\right].
\end{aligned}$$

Dividing this last expression by $f\lambda - \tau\left(a_E+f\right)$ yields

$$\begin{aligned}
&\frac{N_t c}{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}\left[\begin{array}{c} \int_0^{a_L}\frac{\left[f\lambda-(a+f)\right]}{\left[f\lambda-\tau(a_E+f)\right]}g(a)da \\ +\int_0^{a_E}\frac{\left[f\lambda-\tau(a+f)\right]}{\left[f\lambda-\tau(a_E+f)\right]}g(a)da - G(a_E)\end{array}\right] \\
= \quad & \frac{w_H X_t}{\left[f\lambda-\tau\left(a_E+f\right)\right]}\left[F_R + F_L G(a_L)\right],
\end{aligned}$$

then

$$\begin{aligned}
&\frac{N_t c}{f\lambda\left(\rho + \frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}\left[\begin{array}{c} \int_0^{a_L}\frac{\left[f\lambda-(a+f)\right]}{\left[f\lambda-\tau(a_E+f)\right]}g(a)da \\ +\int_0^{a_E}\frac{\left[f\lambda-\tau(a+f)\right]}{\left[f\lambda-\tau(a_E+f)\right]}g(a)da - G(a_E)\end{array}\right] \\
&-\frac{w_H X_t}{\left[f\lambda-\tau\left(a_E+f\right)\right]}F_L G(a_L) \\
= \quad & \frac{F_R w_H X_t}{\left[f\lambda-\tau\left(a_E+f\right)\right]}
\end{aligned}$$

and

$$\begin{aligned}
&\int_0^{a_L} \frac{[f\lambda-(a+f)]}{[f\lambda-\tau(a_E+f)]}g(a)da+\int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]}g(a)da-G(a_E)\\
&-\frac{w_H X_t}{[f\lambda-\tau(a_E+f)]}F_L G(a_L)\frac{f\lambda\left(\rho+\frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}{N_t c}\\
=\;&\frac{F_R w_H X_t}{[f\lambda-\tau(a_E+f)]}\frac{f\lambda\left(\rho+\frac{n}{\mu 2}\left[G(a_L)+G(a_E)\right]-n\right)}{N_t c}.
\end{aligned}$$

From equation (2.31), I can use the fact that $F_E=\frac{\frac{N_t c}{f\lambda}[f\lambda-\tau(a_E+f)]}{\left[\rho+\frac{n}{\mu 2}[G(a_L)+G(a_E)]-n\right]w_H X_t}$ to obtain

$$\begin{aligned}
&\int_0^{a_L} \frac{[f\lambda-(a+f)]}{[f\lambda-\tau(a_E+f)]}g(a)da+\int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]}g(a)da-G(a_E)\\
&-F_L G(a_L)\frac{1}{F_E}\\
=\;&F_R/F_E.
\end{aligned}$$

If I multiply this last equation times F_E, I get

$$\begin{aligned}
&F_E\left[\int_0^{a_L} \frac{[f\lambda-(a+f)]}{[f\lambda-\tau(a_E+f)]}g(a)da+\int_0^{a_E}\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]}g(a)da-G(a_E)\right]\\
=\;&F_R+F_L G(a_L),
\end{aligned}$$

which implies that

$$\left[\int_0^{a_L}\left\{F_E\frac{[f\lambda-(a+f)]}{[f\lambda-\tau(a_E+f)]}-F_L\right\}g(a)da+\int_0^{a_E}\left\{F_E\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]}-F_E\right\}g(a)da\right]=F_R.$$

Using $a_L=a_L(a_E)$, I get

$$\begin{aligned}
D_E(a_E)\;\equiv\;&\int_0^{a_L(a_E)}\left\{F_E\frac{[f\lambda-(a+f)]}{[f\lambda-\tau(a_E+f)]}-F_L\right\}g(a)da+\\
&\int_0^{a_E}F_E\left\{\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]}-1\right\}g(a)da\\
=\;&F_R.\blacksquare
\end{aligned}$$

6.3. Properties of $D_L(a_L)$. I claim that the term $\int_0^{a_L}F_L\left\{\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]}-1\right\}dG(a)$ is increasing in a_L. To see this, notice that $[f\lambda-(a_L+f)]$ is decreasing in a_L, so $\frac{[f\lambda-(a+f)]}{[f\lambda-(a_L+f)]}$ is increasing in a_L and the upper limit of integration is also increasing in a_L. The other term $\int_0^{a_E(a_L)}\left\{F_L\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}-F_E\right\}dG(a)$ is also increasing in a_L since the ratio $\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}$ is increasing in a_L and the upper limit of integration increases since $a_E(a_L)$ is increasing in a_L. Thus $D_L(a_L)$ is increasing in a_L.$\blacksquare$

6.4. Proof of Theorem 1. If τ falls, the ratio $\frac{[f\lambda-\tau(a+f)]}{[f\lambda-(a_L+f)]}$ increases in equation (3.6). The upper limit of integration has to decrease ($a_L \downarrow$) to restore the equilibrium condition $D_L(a_L) = F_R$. To see that a_E increases when τ falls, notice that the ratio $\frac{[f\lambda-(a+f)]}{[f\lambda-\tau(a_E+f)]}$ decreases in equation (3.7) if τ decreases. The second term of (3.7), $\int_0^{a_E} F_E \left\{\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]} - 1\right\} g(a)da$, also decreases if τ falls for given a_L, a_E because

$$\begin{aligned}\frac{\partial\left[\frac{[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]}\right]}{\partial\tau} &= \frac{-(a+f)[f\lambda-\tau(a_E+f)]+(a_E+f)[f\lambda-\tau(a+f)]}{[f\lambda-\tau(a_E+f)]^2} \\ &= \frac{-f\lambda[(a+f)-(a_E+f)]}{[f\lambda-\tau(a_E+f)]^2} = \frac{f\lambda[a_E-a]}{[f\lambda-\tau(a_E+f)]^2} > 0.\end{aligned}$$

Analogously, the LHS of equation (3.7) falls for given a_L, a_E when τ falls. So the upper limit of integration has to increase ($a_E \uparrow$) to restore the equilibrium condition $D_E(a_E) = F_R$.■

6.5. Proof of Lemma 2. A decrease in τ causes a decrease in a_L and an increase in a_E due to Theorem 1. It follows then that $N_{A_+} = \frac{a_E^k}{a_L^k}$ increases. But $N_B = \frac{a_L^k - a_E^k}{a_L^k + a_E^k}$ decreases because $\frac{\partial N_B}{\partial\left(a_E^k/a_L^k\right)} = \frac{\partial\frac{\left(1-a_E^k/a_L^k\right)}{\left(1+a_E^k/a_L^k\right)}}{\partial\left(a_E^k/a_L^k\right)} = \frac{(-1)\left(1+a_E^k/a_L^k\right)-\left(1-a_E^k/a_L^k\right)}{\left(1+a_E^k/a_L^k\right)^2} = \frac{-2}{\left(1+a_E^k/a_L^k\right)^2} < 0.$■

6.6. Properties of Equation (3.9)**.** Now I show that condition (3.9) is a downward sloping curve in $(\varkappa, \theta_0)$ space. Notice that θ_0 only appears in the numerator, then $\frac{d[(\theta_0+1-2\sigma)(1-\theta_0)]}{d\theta_0} = (1-\theta_0) - (\theta_0+1-2\sigma) = -2\theta_0 + 2\sigma = 2(\sigma - \theta_0) < 0$ if and only if $\sigma < \theta_0$. This last inequality holds by construction because it is a necessary condition for the wage rate $(\theta - \sigma) w_H$ to be strictly positive.■

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PAPER 3

Offshoring and the Onshore Composition of Tasks in Swedish Multinationals

Damián Migueles Chazarreta

ABSTRACT. Using plant-level data with information about work composition and foreign activities of Swedish multinational manufacturing firms, I investigate the relationship between firms' foreign expansion and the composition of tasks carried out by the employees of the Swedish plants. I find a negative relationship between offshoring for market access purposes and the cost share of onshore labor force that performs non-routine and interactive tasks.

JEL Classification: F14, F16, F23, J23, J24

Keywords: Horizontal and vertical FDI, Trade in tasks, multinational enterprises, demand for labor, linked employer-employee data.

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1. Introduction

Increased reallocation to other countries of some parts of a firm's activity (offshoring) has created a strong interest in how a transfer of production abroad affects the demand for different types of labor. Several papers have estimated empirically the relationship between measures of such a transfer and the relative demand for skills (Feenstra and Hanson, 1999; Slaughter, 2000; Head and Ries, 2002 and Hijzen, Görg and Hine, 2005). While most papers conclude that a transfer of production is associated with skill upgrading and an increased relative demand for skills in parents firms, other factors such as skill-biased technological change seem more relevant for the overall trend towards skill-upgrading. Moreover, the integration of economies with a large pool of highly educated workers, most notably China, India and Eastern Europe with the rest of the world economy, has created concerns in rich countries over the possibility that also many high-skilled jobs are being offshored. Recent theoretical work[1] on the effects of offshoring certain types of occupations or tasks (instead of production) on the relative demand for skills and the skill premium, show that the effect depends not only on the skill-intensity of the jobs that are being offshored, but also on the sector bias of offshoring itself.

The traditional division into skilled and unskilled labor for analyzing the impact of offshoring has recently been challenged by several authors (e.g. Leamer and Storper, 2001; Markusen, 2005; Jensen and Kletzer, 2006 and Blinder, 2006). They argue that the nature of the performed task may be more relevant for the job's propensity to be offshored than its skill level. For instance, a highly routinized task, which can easily be codified, is more likely to be offshored than a task that requires tacit information, regardless of the skills of the worker (Leamer and Storper, 2001). Similarly, a task that neither needs to interact with other tasks nor needs to be within certain geographic proximity is also more easily offshored. The interpretation of X-ray pictures is an example of such a task that is sometimes offshored but is also skill-intensive.[2] Maintenance work, on the other hand, is highly interactive with the maintained facilities, and therefore, less easily offshored, although it is less skill-intensive. One would expect a skill-intensive task to be relatively more interactive and non-routine than a less skilled-intensive, but the previous example shows that it is not necessarily so.

Classifying tasks according to the degree to which they are routine and interactive, Becker, Ekholm and Muendler, 2009 (BEM from now on); have in a recent empirical

[1] See Grossman and Rossi-Hansberg, 2008 and Baldwin and Robert-Nicoud, 2007.

[2] The transmission of x-rays, CTs, and MRIs, from one location to another for the purposes of interpretation and/or consultation is called teleradiology. Bradley (2004) describes some of the details involved in setting up an offshore teleradiology practice. See also Goldberg (1996) for an historical description.

study focused on task composition. They analyze the relationship between a shift towards producing abroad and the workforce composition at home. Using information on German multinationals enterprises (MNEs) and their employees, they find that an increase in the share of foreign affiliate employment in total employment, is associated with a small (but statistically significant) increase in the share of the wage-bill of not only highly educated workers, but also of occupations carrying out non-routine and interactive tasks.

In this paper, I use a similar approach to analyze the relationship between the expansion of Swedish MNEs[3] abroad and their workforce composition in Sweden. Using a unique data set, I study the relationship between the wage-bill share of non-routine and interactive tasks in the Swedish plants of Swedish MNEs and the MNEs' expansion abroad. The data set is constructed from several data sources. The two most noteworthy are: *i*) a plant-level data base containing information about Swedish manufacturing plants and their production activities abroad, and; *ii*) a worker-level data base on employees in the private sector. I use these two and create a linked employer-employee data set where the unit of observation is the plant; with worker, plant and MNE level information. An important difference from BEM is that I have plant-level information on intra-firm trade between foreign affiliates and their Swedish parents. That enables me to distinguish between foreign affiliate activities generated by the desire to get better market access (horizontal FDI) and those related to the production of inputs used by the parent plant (vertical FDI), which more closely captures the notion of "offshoring" (even if it is here restricted to so-called "in-house" offshoring). To the best of my knowledge, this is the first study that uses data on intra-firm trade to distinguish between vertical and horizontal FDI in order to assess its impact on the cost shares of different tasks in the home location. I also have information about research and development (R&D) activities of the MNEs, which enables me to control for the effect of innovative activities on the work composition of the plant.

The empirical strategy I use is similar to the cost function estimation used in related work on MNEs (e.g. see Slaughter, 2000; Head and Ries, 2002; Hanson, Mataloni and Slaughter, 2005; Harrison and McMillan, 2006; Hansson, 2005; and BEM, 2009). I reduce the econometric specification to a single reduced-form cost-equation, where the left-hand side variable is the wage-bill share of either interactive tasks or non-routine tasks in a Swedish plant. I also study the wage-bill share of white-collar workers to compare my results with the previous literature. Contrary to BEM, I do not find any statistically significant relationship between total worldwide offshoring and any of these

[3] A Swedish MNE is a corporation with headquarters in Sweden that operates in two or more countries where the production or marketing facilities outside the headquarters are the results of FDI.

wage-bill shares. However, offshoring driven by market access motives is negatively related to the wage-bill share of interactive as well as non-routine tasks. This is a somewhat surprising result that is not immediately consistent with standard theories of offshoring.

The rest of the paper is organized as follows: In Section 2, I discuss the theoretical background and related empirical work; in Section, 3 the estimation strategy is presented. In Section 4, I introduce the data, discuss variable construction and present a first look at some descriptive statistic. In Section 5, I discuss the results of the econometric specification and in Section 6, I give some concluding remarks, including remarks on possible interpretations of the findings in the paper.

2. Background and related literature

A seminal contribution on the classifications of job tasks was the study by Autor et al. (2003) where they study how the use of computers has affected relative demand for job tasks. They classify job tasks into five categories: routine cognitive tasks, routine manual tasks, non-routine analytical tasks, non-routine interactive tasks and non-routine manual tasks, and show that the shares of non-routine analytical and non-routine interactive tasks in the U.S. increased from 1960 to 1998.

The importance and volume of offshoring and in particular the role of MNEs has increased over time, as transport costs fall and communication technologies improve. Grossman and Rossi-Hansberg (2008), for instance, estimate that about 47 percent of U.S. imports were conducted within MNEs in 2005. In addition, this trade is not predominantly in final goods, but in intermediate inputs and small parts of processes. This fragmentation of production processes involves performing different tasks in different locations (see Jones and Kierzkowski, 2001 and Grossman and Rossi-Hansberg, 2008). Given MNEs presence in different markets, they are better able to adapt to production cost differentials across countries and we would therefore expect them to have a higher degree of specialization in production and job tasks depending on these cost differentials. There are several theoretical models of offshoring[4] although just a few have studied the different tasks involved in offshored activities. Grossman and Rossi-Hansberg (2008) model offshoring as trade in tasks rather than as trade in intermediates. In their model, the sectors in which offshoring takes place can experience a rise in productivity which benefits the type of worker whose tasks are being offshored. On the other hand, the fall in the relative price of the good that intensively uses the offshored task in its production, works in the other direction.

[4] See e.g. Jones and Kierzkowski (1990) and Feenstra and Hanson (1996) for early contributions and Barba and Navaretti (2008) for a recent survey.

In line with the idea that tasks are associated with a degree of offshorability according to their degree of routine and non-interactive components, Blinder (2009) uses occupational codes from the Standard Occupational Classification (SOC) system to construct indexes that indicate whether a job can be done elsewhere or if it has to be done on the site. His index indicates that approximately 25 percent of all U.S. jobs is potentially offshorable.

Similar to the questions asked here, but focusing on skills rather than on tasks, other studies investigate the effect of offshoring on relative demand for skilled labor. Feenstra and Hansson (1999) estimate that offshoring of intermediate input production by U.S. industries (not only MNEs) can explain between 15 to 40 percent of the increase of the wage-bill share of the skilled non-production workers.[5] Other studies point out, however, that the reported effects of affiliate activities on the relative demand for skills in the parent plants are relatively small when only MNEs are considered. Slaughter (2000), for instance, using industry data for U.S. manufacturing MNEs, finds no support for the hypothesis that transfer of production within MNEs has contributed to U.S. skill upgrading within industries. Head and Ries (2002), using a similar approach for Japanese manufacturing MNEs, find a statistically significant effect (although small) of foreign affiliate employment expansion on the wage-bill share of non-production workers. One possible explanation for these results is that a large portion of MNEs' offshoring is intended for market access (horizontal FDI) rather than production of intermediate inputs (vertical FDI) motivated by cost differentials.[6] Horizontal FDI may be largely expected to replicate, the same skill composition as the MNE has at home. Evidence for this has been presented by Hansson (2005). He shows that offshoring has effects on the wage-bill share of Swedish MNE manufacturing workers with post-secondary education, only when offshoring is directed to non-OECD countries.

My paper has the advantage that, in addition to a detailed geographical classification of host countries, I have affiliate data from which I can construct horizontal and vertical FDI measures, which are absent in all previous studies.[7] Horizontal FDI, where MNEs mostly replicate the same production in different locations for market access, implies that the MNE essentially performs the same range of production activities in

[5] In industrialized skilled-abundant countries, offshoring is expected to increase the relative demand for skilled labor and nonproduction workers are on average more skilled than production workers (see Head and Ries, 2002).

[6] Barba Navaretti and Venables (2004, chapters 2 and 3) present evidence that horizontal -market seeking- FDI is the predominant type of FDI between high-income countries.

[7] Previous studies (e.g. Hanson, 2005; Head and Reis, 2002 and BEM, 2009) try to distinguish between horizontal and vertical FDI by grouping offshoring destination countries into different income levels. This assumes that low-income countries are typically recipients of vertical FDI.

its plants. We would therefore expect MNEs engaging in horizontal FDI, to have a task composition offshore, similar to that in the onshore plants. This contrasts with vertical FDI where each offshore plant produces a different input (or stage of production) of the plant's production process in order to minimize costs. I would expect tasks that can easily be codified and summarized into deductive rules (routine tasks) and tasks where geographic proximity and physical contact are of minor importance (non-interactive tasks), to be more prone to be offshored in such circumstances.

3. Estimation Strategy

I follow Slaughter (2000), Head and Ries (2002), Hansson (2005) and BEM (2009), among others, by assuming that firms minimize costs captured by a translog cost function. This translates into a reduced-form equation of the following type:[8]

$$\theta_{ijt} = \Sigma_l \beta_l OE_{klt} + \beta_K \ln \frac{K_{kt}}{Y_{kt}} + \beta_Y \ln Y_{jt} + \beta_\omega \ln \frac{\omega_{ijt}}{\omega_{-ijt}} + \alpha_j + \alpha_t + \varepsilon_{ijt} \tag{3.1}$$

where the left-hand-side (LHS) variable θ_{ijt} is the wage-bill share of task or occupation i out of the total wage bill in plant j in year t. Assuming that routine and non-interactive tasks are more easily offshored, one would expect that offshore activities have contributed towards more interactive and non-routine work in onshore locations. The tasks I compare are routine (i) vs non-routine $(-i)$ and interactive (i) vs non-interactive $(-i)$. In order to compare to previous work and to proxy for skills, I also distinguish between white-collar occupations (i) and blue-collar occupations $(-i)$. I Use this dichotomous classification in order to compare my results with the work of BEM, Head and Ries (2002) and Slaughter (2000), among others.

The variable of main concern is OE that measures "*Offshore Employment*" of work type l at the parent level for MNE k in year t. The type index l indicates *i)* the income level (high or low) of the offshore location; *ii)* an exhaustive geographical/economic classification of the offshoring location (Western Europe, WE; Other Industrialized Countries, OIC; Eastern Europe, EE and Other Developing Countries, ODC) and *iii)* whether the FDI conducted in the offshore location is horizontal or vertical FDI. If l refers to the income level of the geographical/development classification, I construct OE by adding up MNE k´s offshore employment in all l-countries as a share of total MNE employment:[9]

$$OE_{klt} = \frac{\Sigma_{n \in l} x_{nt}}{\Sigma_{j \in k} x_{jt} + \Sigma_{n \in l} x_{nt}} \tag{3.2}$$

[8] See Feenstra (2009), pages 76-77 for a derivation.

[9] This strategy is similar to the one used by Head and Ries (2002), Hansson (2005) and BEM (2009).

where x_{nt} is the employment of MNE k's offshore affiliate n in location l at time t, and x_{jt} is the employment in MNE k's onshore plant j at time t.

One significant advantage of the data set of is that I have information on intra-firm trade. Using that information I construct a variable that measures whether the MNE's offshoring is conducted for horizontal or vertical FDI purposes. More precisely, for proxying for a MNE's horizontal FDI in a particular offshore location, I use the offshore location's share of sales to its own market and to all other offshore markets, excluding Sweden. I then estimate the number of employees the offshore location uses in horizontal activities. To do that, I assume that the share of sales to all offshore markets is the same as the share of employees in horizontal activities and that workers are allocated linearly in different activities. All other sales are those sales that have Sweden as its destination market and I assume that these sales constitute intermediary parts in a vertically integrated process. In consequence, I assume that the share of sales to Sweden is also the share of employees devoted to vertical activities in the offshore location. Using this criterion, x_{nt} is then MNE k's offshore employment in either horizontal or vertical FDI sales of affiliate n in location l. Thus, if a Swedish MNE has 100 employees in a plant in Argentina, and all its sales go to Brazil and Argentina, then all of its offshore employment in Argentina work in Horizontal FDI related activities. To obtain a measure of MNE k's total offshore employment in either horizontal or vertical FDI, $\Sigma_{n \in l} x_{nt}$, I just sum over all l locations.

The previous measure implicitly assumes that affiliate production for export to third countries, known as export-platform FDI, is horizontal FDI. Given that that might not necessary be the case, I also construct a more restrictive measure of horizontal offshoring: Instead of using the offshore location's share of sales to all offshore markets as a measure for horizontal offshoring, I only consider the offshore location's share of sales to "its own market" as a measure of horizontal activities. So, according to the previous example, only 50 percent of its offshore employment in Argentina works in Horizontal FDI related activities.

The ratio K_{kt}/Y_{kt} is the capital-output ratio at the parent-MNE level k, Y_{jt} is real output in firm j, w_{ijt} is the average hourly wage for carrying out task or occupation i in plant j while w_{-ijt} is the average hourly wage of the complementary task or occupation. I include a firm-specific effect (α_j), a year effect (α_t) and a iid error term (ε_{ijt}).

The identifying assumption of the econometric specification is that offshore employment and capital are quasi-fixed factors at the time of the onshore workforce choice. This imposes a sequence that indicates that exogenous changes in offshoring costs causes faster adjustments on onshore tasks than on offshore employment. I also assume that the capital to output ratio K_{kt}/Y_{kt} controls for unobserved capital costs specific to each MNE and accounts for variation in the wage-bill share θ_{ijt} that is explained by capital deepening. The estimate of β_Y shows whether growth in output in plant j is related to the wage-bill share of task or occupation i. If $\beta_Y = 0$, the hypothesis that the production function is homothetic cannot be rejected. The wage ratio $\omega_{ijt}/\omega_{-ijt}$ accounts for variation in the wage-bill share due to relative factor prices. The plant-specific effect α_j controls for unobserved time-invariant plant heterogeneity. Year dummies control for changes in the workforce composition that affect all plants. Variations of equation (3.1) include controls for R&D intensity to proxy for technical change and an industry-specific average wage-bill share of task or type i in plants of non-MNEs for controlling for industry-specific common trends in wage-bill shares that affect all plants.

The key question of the study is whether the coefficient β_l is statistically different from zero (the null hypothesis). If $\beta_l > 0$, then higher levels of offshore employment are associated with higher wage-bill shares of task i and it will provide evidence that offshoring has contributed to change the type of activities the onshore workforce performs.

Potential weaknesses of the model, in addition to measurement errors and attrition, are problems caused by simultaneous determination of offshore employment at location l and onshore demand for task i, which might bias β_l. An instrumental variable regression could be a way of getting around this problem, but I have not been able to find a sufficiently consistent and strong instrument. Another concern is that cross-sectional variation of the relative wage term $\omega_{ijt}/\omega_{-ijt}$ might be the consequence of compositional changes rather than exogenous wage differences. Under the assumption of perfect labor mobility between industries, there will be no cross-sectional wage variation implying that $\omega_{ijt}/\omega_{-ijt}$ is a constant for a given t and could then be accounted for in the year dummies. Following previous work[10] I include this term in a baseline specification, but also omit it for robustness check.

4. Data and Descriptive Statistics

The results derive from the combination of four data sources: a micro-data source from the Confederation of Swedish Enterprise (Svenskt Näringsliv, SN); the German Institute for Vocational Training (Bundesinstitut für Berufsbildung, BIBB) and the Research Institute of the German Federal Labor Agency (Institut für Arbeitsmarkt und Berufsforschung, IAB) work survey (BIBB-IAB, from now on); and two data sources at the MNE and offshore plant level from The Research Institute of Industrial

[10] See Berman et. al. (1994), Feenstra and Hanson (1996), Autor et al. (1998), Machin and Van Reneen (1998), Hansson (2000), Slaughter (2000) and Head and Ries (2002).

Economics (Institutet för Näringslivsforskning, IFN). I use two additional sources for linking the SN and IFN databases. By linking employer and employee data, I construct a data set with an onshore plant of a Swedish MNE as the unit of analysis.

4.1. Data sources. The onshore plant data is at the worker-job level and comes from a confidential database collected annually by SN up to 2003. It is assembled from wage reports provided by SN member firms. The data contain information on blue and white-collar workers in every industry (except the bank and insurance sectors) and cover about 40 percent of all workers in the private sector and about 24 percent of the Swedish labor market.[11] The database contains plant, worker and job characteristics. Plant characteristics recorded in the data include industry code, plant code and plant size (represented by number of employees). Worker and job characteristics include earnings in each pay system (piece or time rate for blue-collar workers and monthly wage for white-collar workers and other payments such as overtime and bonuses), worker age, number of hours worked and occupational code. Occupational codes are three-digit codes (the codes exist up to the four-digit level) describing the occupation or job titles. This coding, compiled by Statistics Sweden, is called "Standard for Swedish Job Classification" (Standard för Svensk Yrkesklassificering, SSYK-96[12]) and consist of 113 occupational groups at the three-digit level, describing the type of job and tasks workers perform. In this study, I work at the two-digit level, which reduces the number of groups to 27. For matching purposes, I translate these codes into the International Standard Classification of Occupations code classification (ISCO-88), the classification followed by the International Labor Organization (ILO).

The second data source is the BIBB-IAB work survey[13]. BEM classified the answers in the BIBB-IAB work survey, according to their implications for whether the workers tend to carry out non-routine and interactive tasks on the job. Like them, I codify the tasks involved in an occupation (represented as an ISCO-88 code) as non-routine and interactive. For instance, according to this mapping, the ISCO-88 code 21 (Physical, mathematical and engineering science professionals) is 100 percent non-routine and 44 percent interactive; the ISCO-88 code 33 (teaching associate professionals) is 67 percent interactive and 58 percent non-routine, and so on. The worker-job information is then aggregated at the onshore plant level where I use this task classification to create the wage-bill shares for different tasks (i.e. interactive and non-routine) and occupations (blue and white-collar workers).

[11] See Ekberg (2004), for a more in-depth discussion of the data.

[12] SSYK-96 builds upon the ISCO-88 classification and replaces the older Nordisk Yrkesklassificering (NYK83).

[13] BEM have a lengthy discussion of the BIBB-IAB survey and how the codification was done.

Data on Swedish MNEs and their offshore activities come from a confidential survey of Swedish multinationals called "Activities of Swedish MNEs Abroad" (SMNEA-IFN), collected and assembled in IFN. This data source offers parent information (SMNEA-A) of Swedish manufacturing MNEs and the activities of their producing affiliates abroad (SMNEA-B). Parent and offshore affiliates information include data on employees, exports and imports by region, turnover, revenues, expenditure, assets, R&D, etc. These surveys cover virtually all Swedish MNEs in manufacturing but exhibit falling response frequencies.

To combine the SN and IFN data sources I use *i*) a commercial database on holding structures from the Business Register from Statistics Sweden, and *ii*) SN's annual directory (SAF Matrikel, 1978-1995). The Business Register from Statistics Sweden allows us to identify all onshore affiliates of those MNEs in the SMNEA-A data source with their names and the Swedish firm-ID (organisationsnummer). The name and firm-ID used by SN (delägarnummer) is documented in the SAF Matrikel, which lets me find the corresponding firm in the SN data source. The result of this matching process is onshore plant-level data with information on its employees, industry and characteristics of the MNE they belong to. Most importantly, I also manage to distinguish the offshore intensity by location, income and whether the activities conducted abroad are horizontal or vertical FDI. When creating plant level controls such as turnover (as a measure of output), R&D and capital, I use the parent´s values, allocating to the onshore affiliate according to its share in parent employment. The base year for deflating nominal values is 1994.[14]

I use the information in the SN data excluding the matched sample to control for common trends in wage-bill shares at the industry level. The econometric specification together with missing data for some of the covariates reduces the amount of observations that can be used. In addition, not all MNEs in the IFN data could be found in the SN data. Plants in the regressions are typically relatively larger, and they belong to large Swedish firms and to relatively large MNEs. So although not representative for the whole population, it allows me to capture a significant share of the workforce in the manufacturing industry. In Table 1, the number of employees in Swedish MNEs and those present in the main regression are shown: around 108000 employees in 1995, 124000 employees in 1999 and 86000 in 2003. The resulting matched sample captures approximately 30 and 35 percent of all employees of Swedish manufacturing MNEs for years 1994 and 1998, respectively, and 25 percent for 2003.

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[14] The price deflator used is the Producer Price Index (PPI), except for construction companies that were deflated using the Housing Price Index (Bostadprisindex, BPI).

TABLE 1. Number of Employees In Different Samples of Swedish Manufacturing MNEs

	Total*	Matched SN-IFN	In Regressions
1995	376,680	244,855	108,777
1995	349,640	225,861	124,316
2003	225,248	182,546	86,288

*Source: Statistics Sweden

4.2. Variable Construction. To codify tasks involved in an occupation, I use the classification made by BEM. They codify their survey answers to 81 yes/no questions that ask whether a worker uses a specific workplace tool or not. The 81 workplace tools range from hand tools to machinery and diagnostic devices to computers and means of transport. The use of a particular tool indicates whether its use implies a non-routine task (characterized by non-repetitive methods of work) and whether its use implies an interactive task (characterized by frequent personal interaction with coworkers, suppliers or customers). They end up mapping 84 ISCO-88 job classifications at the 2-digit level to a number between 0 and 1 according to its interactive/non-interactive and routine/non-routine[15] intensity. In my data set, given that I focus on the manufacturing industry, I end up using 28 different ISCO-88 codes only. Science based and engineering occupations have the highest share of non-routine tasks, and workers in mining, construction, manufacturing and transport have the lowest. The most interactive jobs are those performed by life science, health and teaching professionals and the least interactive jobs are those performed by machine operators, handicraft workers and some sales and services occupations. Blue-collar workers are more represented in non-interactive and routine tasks than white-collar workers.

BEM also provide a combined non-routine and interactive measure. This combined measure and the original routine and interactive activities measures come in two different versions: a liberal and a conservative one. I use BEM's different versions in order to assess robustness.[16]

4.3. A First Look at the Data. Swedish MNEs have expanded significantly over the last decade and have allocated an increasing share of its workforce abroad. From having less than 45 percent of its workforce offshore in 1995, the share increased to almost 65 percent in 2003 for my sample (see Table 2).

[15] Notice that these two classifications are not exhaustive so a task can for instance be 80 percent interactive and 80 percent non-routine.

[16] Available upon request.

The onshore workforce composition has also changed in Swedish MNEs and there has been an overall shift towards more interactive and non-routine tasks, as indicated in the first column of Table 3 that reports the changes of wage-bill shares for the time period 1995-2003. In the same table, columns 2 and 3 show the wage and employment contributions to the total wage-bill change according to the following expression:

$$\frac{\theta_{it}-\theta_{i0}}{\theta_{i0}} = \left(\frac{L_{it}}{L_{i0}}\frac{\omega_{it}-\omega_{i0}}{\omega_{i0}} - \frac{L_{-it}}{L_{-i0}}\frac{\omega_{-it}-\omega_{-i0}}{\omega_{-i0}}\right)\Psi_i + \left(\frac{L_{it}-L_{i0}}{L_{i0}} - \frac{L_{-it}-L_{-i0}}{L_{-i0}}\right)\Psi_i \tag{4.1}$$

where

$$\Psi_i = (1-\theta_{i0})\,\frac{\omega_{i0}L_{i0}-\omega_{-i0}L_{-i0}}{\omega_{it}L_{it}-\omega_{-it}L_{-it}}.$$

The left hand side of equation (4.1) is the percentage change of the wage-bill share of task i from time 0 to t. The first term between parentheses in the right hand side of equation (4.1) constitutes the contribution of the wage component and the other term constitutes the contribution of the employment component to this overall change. L_{it} is the employment of work type i, ω_i is the wage of work type i and ω_{-i}

TABLE 2. Offshoring of Swedish Manufacturing MNEs. Data from the Regression Sample

	1995	1998	2003
Employees Offshore/Total	.432	.496	.637
Employees High Income Countries/Total	.357	.376	.484
Employees Low IncomeCountries /Total	.074	.119	.155
Employees Western European Countries/Total	.244	.252	.305
Employees Other Industrialized Countries/Total	.112	.120	.173
Employees Eastern European Countries/Total	.019	.039	.055
Employees Other Developing Countries/Total	.056	.084	.106
Employees Horizontal[a]/Total	.299	.295	.280
Employees Vertical[b]/Total	.133	.169	.086
Employees Horizontal2[c]/Total	.412	.424	.345
Employees Vertical2[d]/Total	.021	.039	.021

[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).
[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets.
[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets, excluding Sweden (less restrictive measure).
[d]Share of total employment in offshore locations producing for exports to Sweden.

is the complementary work or employment type not in i. Results in columns 2 and 3 indicate that for the whole period 1995-2003, most of the total change is due to changes in employment rather than changes in relative wages. For non-routine and interactive tasks, employment shifts explain around 65 percent of the wage-bill change. The positive correlation between wage and employment contributions suggests that labor demand shocks rather than labor supply shocks were the underlying cause.

TABLE 3. Decomposition of Wage-Bill Changes

	Total Change	Wage Component		Employment Component	
		Contrib.	Percent	Contrib.	Percent
Non Routine 95-03	.057	.020	35	.037	65
Non Routine 95-98	.010	.008	80	.002	20
Non Routine 98-03	.045	.015	33	.030	67
Interactive 95-03	.054	.020	37	.034	63
Interactive 95-98	.007	.008	114	-.001	-14
Interactive 98-03	.045	.015	33	.030	67

TABLE 4. Correlations Between Initial Cost Shares and Offshore Expansion 1995-2003

	Share White Collars	Share Non-Routine	Share Interactive
Low Income Countries	-.1345*	-.1259*	-.1610**
High Income Countries	.1183*	.0537	.0284
Western European Countries	.0591	-.0457	-.0504
Other Industrialized Countries	.1917***	.2529***	.1931***
Eastern European Countries	-.0682	-.1145*	-.1661**
Other Developing Countries	-.1313*	-.0590	.0504

*,**,*** Correlation coefficients significant at the 10, 5 and 1 percent level respectively.

Table 4 shows correlations between changes in the share of offshore employment (defined as the ratio of employees abroad to total employees in the MNE) for the time span 1995-2003 and the plants' initial wage-bill share of different work types. There are significant negative correlations between the change in offshoring to low-income countries and the wage-bill share of all "advanced" work types, i.e., white-collar occupations and non-routine and interactive tasks. The opposite occurs for high-income countries, but only the correlation with the wage-bill share of white-collar workers is significant at the ten-percent level. If we consider a more disaggregated geographical classification, it can be seen that only the correlation between the change in offshoring to other industrialized countries and the wage-bill share is significant for all "advanced" work types; while the change in offshoring to Eastern European countries and the wage-bill share of non-routine and interactive tasks are negatively correlated. Thus, offshoring to low-income countries seemed to occur more frequently in MNEs with a relatively low wage-bill share of white-collar workers performing relatively few non-routine and interactive tasks in Swedish plants. Offshoring to high-income countries occurred more frequently in MNEs with a relatively high wage-bill share of white-collar workers and with workers performing non-routine and interactive tasks in Swedish plants. Interpretations regarding the association between cost shares and offshore expansion must be done with caution given that these correlation coefficients are rather small.

4.4. Estimation Results. In order to investigate the relation between offshore expansion and onshore wage-bill shares I estimate equation (3.1) for non-routine tasks, interactive tasks and for white-collar workers. In the main specification, I have limited the analysis to the time span 1995-1999 because of a low-response frequency in the SMEA questionnaire of 2003 (results do not change if 2003 is included and I show them for the whole sample in The Appendix).[17] I end up having at most 126 onshore plants belonging to 33 different Swedish MNEs observed in two time periods. While the number of observations is rather low, we note that it represents a significant percentage of Swedish manufacturing employment as discussed in Section 4.1.

Non-routine and interactive tasks, total offshoring. I start by presenting results for total, worldwide offshoring. The presented results are based on a conservative measure of non-routine and interactive tasks. Results with a more lenient classification provide similar results and are available upon request. In Table 5, I present the results for non-routine tasks and the results for interactive tasks in Table 6. The point estimates for the offshoring variable show the estimated change in the wage-bill share, which is defined as a ratio between 0 and 1, associated with a one unit increase in the offshoring measure, which is defined by equation (3.2). In both tables, the first column shows results for total offshoring and the second and third columns show results for offshoring according to income and geographical/economic classifications. In Table 5, where non-routine tasks' wage-bill share is the dependent variable, contrary to what BEM find, I do not find any statistically significant coefficient of total offshoring. In the data, a major part of the offshore activities are horizontal FDI (rather than vertical

[17] Before 1995 the job code classification SN followed could not be translated into ISCO88 codes. The IFN database includes years up to 2003, but a low response frequency in the SMNEA-B 2003 survey reduces the number of observations to less than 10. Therefore I present regressions for the time span 1994-1999 and include 2003 for robustness checks in The Appendix.

FDI), motivated by improved market access, rather than cost differentials. This may potentially explain the difference in results. Opening an affiliate abroad in a country with similar relative factor endowments may result in similar task intensities the MNE had at its headquarters and might, therefore, have very modest effects at the parent.[18] As in BEM, however, I find that offshoring to low-income countries has a positive relationship with the non-routine wage-bill share; but this result is not robust when 2003 is included in the sample (see The Appendix). In line with this result, I also find a positive relationship between offshoring to other developing countries (which are typically low-income) and the wage-bill share of non-routine tasks onshore; although this coefficient is only significant at the ten-percent level when 2003 is included. In Table 6, where interactive tasks' wage-bill share is the dependent variable, similar results are obtained, but here, there are no significant estimates of the coefficients of offshoring to particular regions.

In their study, BEM find offshoring to be positively correlated with both non-routine and interactive tasks' wage-bill share. This is something I would have expected for Swedish MNEs, particularly when offshoring to low-income countries and to developing countries where there are significant wage differentials and where vertical FDI is more likely to be performed. As discussed previously, horizontal operations, on the other hand, are mainly intended for market access and might, therefore,to a large extent replicate the same skill composition the MNE had at home.

Non-routine and interactive tasks, vertical and horizontal offshoring. Tables 7 and 8 show the regressions of the wage-bill share of non-routine and interactive tasks when offshoring is divided into horizontal and vertical FDI. In order to compare to previous work and to proxy for skills, in Table 9 I also present results for the wage-bill share of white-collar occupations.

In Table 7, the dependent variable is the wage-bill share of non-routine tasks. In the first column, I use the narrow definition of vertical and horizontal FDI and in the second the broader criterion. In the third column, the plant relative wage $\omega_{ijt}/\omega_{-ijt}$, which among the regressors is the one most likely to suffer from simultaneity problems, is omitted from the main specification in order to see whether endogeneity problems might be driving the results.

The estimated coefficients for offshore employment in horizontal FDI are negative and significant at the 5-percent and 10-percent levels depending on whether the narrow or broader definition is used. The values of the coefficients are low, however. The

[18] Hansson (2005) presents evidence that support this view. He finds statistically significant effect of offshoring to non-OECD countries on the wage-bill share of manufacturing workers at Swedish MNE with post-secondary education, but no effect of offshoring to OECD countries.

TABLE 5. Offshoring and the Wage-Bill Share of Non-routine Tasks

Variable	(1) Total	(2) By Income	(3) By Region
firm relative wage	0.2123	0.2850	0.2885
	(0.249)	(0.267)	(0.270)
industry wage-bill share	0.5214***	0.5320***	0.5218***
	(0.124)	(0.117)	(0.102)
log Cap/Turnover	-0.0457	-0.0059	-0.0091
	(0.036)	(0.028)	(0.030)
log Turnover	-0.0177**	-0.0218**	-0.0217**
	(0.008)	(0.009)	(0.008)
R&D/Output	0.3209	0.6110***	0.5891**
	(0.316)	(0.194)	(0.241)
year= 1999	0.1630**	0.1970**	0.1997**
	(0.076)	(0.083)	(0.081)
Total Offshoring	-0.1037		
	(0.136)		
Share of Employment in HI countries		-0.1064	
		(0.079)	
Share of Employment in LI countries		0.4405**	
		(0.204)	
Share of Employment in WE			-0.0373
			(0.105)
Share of Employment in OIC			-0.2902
			(0.273)
Share of Employment in EE countries			0.0254
			(0.305)
Share of employment in ODC countries			0.5461***
			(0.186)
Observations	252	252	252
Number of unique plants	126	126	126
Adjusted R^2	0.327	0.357	0.366

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC), Eastern Europe (EE) and Other Developing Countries (ODC).

coefficient indicates that an increase from 0 to 1 in the share of offshore employees involved in horizontal production, is associated with a 0.16 decrease in the wage-bill share of non-routine tasks. Tables 5 and 7 suggest that larger plants, in terms of turnover, tend to spend a smaller share of wage costs paying for non-routine tasks, although the coefficients are small. The plant specific relative wage of non-routine task shows no significant relationship. R&D intensity, however, has a positive and significant estimated coefficient in most specifications.

TABLE 6. Offshoring and the Wage-Bill Share of Interactive Tasks

Variable	(1) Total	(2) By Income	(3) By Region
firm relative wage	0.5547*	0.4749*	0.4933*
	(0.279)	(0.264)	(0.276)
industry wage-bill share	0.6944***	0.7221***	0.7138***
	(0.180)	(0.175)	(0.173)
log Cap/Turnover	-0.0205	-0.0027	0.0002
	(0.014)	(0.014)	(0.016)
log Turnover	-0.0108**	-0.0117**	-0.0131***
	(0.004)	(0.005)	(0.004)
R&D/Output	-0.0275	0.1700	0.2662
	(0.114)	(0.149)	(0.160)
year= 1999	0.0956**	0.1023**	0.1111**
	(0.042)	(0.044)	(0.043)
Total Offshoring	-0.1148		
	(0.075)		
Share of Employment in HI countries		-0.0596	
		(0.047)	
Share of Employment in LI countries		0.1628	
		(0.109)	
Share of Employment in WE countries			-0.0909
			(0.068)
Share of Employment in OIC countries			0.0981
			(0.164)
Share of Employment in EE countries			0.0881
			(0.130)
Share of Employment in ODC countries			0.2137
			(0.136)
Observations	252	252	252
Number of unique plants	126	126	126
Adjusted R^2	0.274	0.277	0.283

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC) Eastern Europe (EE) and Other Developing Countries (ODC).

Turning to interactive tasks, results are presented in Table 8, where the dependent variable is the wage-bill share of interactive tasks. The estimated coefficients for offshore employment in horizontal FDI are negative and significant at the 5-percent level when using the narrow definition and 1-percent for the broader definition. These results are robust to the specification in column 3 and indicate a similar pattern for non-routine and interactive tasks in terms of their relationship with offshoring. As it is for non-routine tasks, plants that are larger in terms of turnover tend to spend a

TABLE 7. Vertical and Horizontal Offshoring and the Wage-Bill Share of non-routine Tasks

Variable	(1) By Type	(2) By Type 2	(3) No firm relative wage
firm relative wage	0.3246	0.3048	
	(0.316)	(0.289)	
industry wage-bill share	0.5358***	0.5510***	0.5226***
	(0.138)	(0.137)	(0.123)
log Cap/Turnover	-0.0329	-0.0281	-0.0264
	(0.048)	(0.044)	(0.048)
log Turnover	-0.0199**	-0.0171*	-0.0175**
	(0.008)	(0.009)	(0.007)
R&D/Output	0.3441*	0.5526***	0.3472*
	(0.190)	(0.181)	(0.182)
year= 1999	0.1751**	0.1586*	0.1594**
	(0.081)	(0.086)	(0.071)
Offshore Employment in Horizontal[a] FDI	-0.1623**		-0.1632**
	(0.068)		(0.069)
Offshore Employment in Vertical[b] FDI	0.0496		0.0597
	(0.183)		(0.183)
Offshore Employment in Horizontal 2[c] FDI		-0.1375*	
		(0.071)	
Offshore Employment in Vertical 2[d] FDI		1.3032	
		(0.966)	
Observations	220	220	220
Number of unique plants	110	110	110
Adjusted R^2	0.338	0.345	0.335

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.,
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC), Eastern Europe (EE) and Other Developing Countries (ODC).
[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).
[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets.
[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets, excluding Sweden (less restrictive measure).
[d]Share of total employment in offshore locations producing for exports to Sweden.

smaller share of wage-costs in interactive tasks less frequently. A difference from the results in Table 7 is that here the plant-specific relative wage of interactive to non-interactive tasks shows a significant positive relationship (although not robust to all specifications) and R&D intensity is only significant when omitting the plant specific relative wage.

Table 8. Vertical and Horizontal Offshoring and the Wage-Bill Share of Interactive Tasks

Variable	(1) By Type	(2) By Type 2	(3) No firm relative wage
firm relative wage	0.5704*	0.5854*	
	(0.308)	(0.311)	
industry wage-bill share	0.7114***	0.7124***	0.5408**
	(0.208)	(0.203)	(0.211)
log Cap/Turnover	-0.0072	-0.0047	-0.0036
	(0.018)	(0.017)	(0.023)
log Turnover	-0.0115**	-0.0117**	-0.0092**
	(0.005)	(0.005)	(0.004)
R&D/Output	0.0031	-0.0131	0.1310**
	(0.092)	(0.127)	(0.054)
year= 1999	0.1020**	0.1040**	0.0826*
	(0.045)	(0.048)	(0.042)
Offshore Employment in Horizontal[a] FDI	-0.1045**		-0.1103**
	(0.039)		(0.045)
Offshore Employment in Vertical[b] FDI	-0.0763		-0.0406
	(0.096)		(0.097)
Offshore Employment in Horizontal 2[c] FDI		-0.0999***	
		(0.035)	
Offshore Employment in Vertical 2[d] FDI		-0.1892	
		(0.472)	
Observations	220	220	220
Number of unique plants	110	110	110
Adjusted R^2	0.290	0.290	0.246

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC), Eastern Europe (EE) and Other Developing Countries (ODC).
[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).
[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets.
[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets, excluding Sweden (less restrictive measure).
[d]Share of total employment in offshore locations producing for exports to Sweden.

Table 9 shows the corresponding results for white-collar workers. There is no significant relationship between effects on the wage-bill share of white-collar occupations and horizontal FDI offshore expansion. The estimated coefficient on vertical FDI is significant, though, suggesting that vertical FDI expansion is positively correlated with the wage-bill share of skilled workers. This result is intuitive and in line with the result in BEM, as one would expect that both Sweden and Germany that have comparative advantages in skill-intensive activities, will reallocate low-skill jobs when production of inputs used by the parent plant reallocate offshore. Moreover, Table 9 also indicates that the white-collar wage-bill share is positively correlated with expansion in low income and other developing countries, categories more abundant in low-skilled workers. These results, however, are neither robust to the broader criterion of vertical FDI nor to including 2003 in the regression (see The Appendix).

Some of the results presented are at odds with the ex-ante hypothesis, namely that offshoring of Swedish MNEs increases the wage-bill share of interactive and non-routine tasks. One possible explanation for this result is that most of Swedish MNEs offshore activities are intended for market penetration (horizontal FDI) rather than labor cost reductions and may, therefore,to a large extent replicate the onshore task composition. However, when regressing on vertical and horizontal FDI, the results are even more surprising. Onshore activities seem to be more routine and less interactive in MNEs with a relatively large expansion abroad for market access reasons. There are not to my knowledge theoretical models that predict these results or empirical work showing similar results. One exception is Hakkala, Heyman and Sjöholm (2010) that find that offshoring to high-income countries reduces the demand for non-routine tasks whereas offshoring to low-income countries has no statistically significant effect[19]. Even though offshoring to high-income countries shows no statistically significant effect in my data, horizontal FDI is typically directed to high-income countries in the case of Sweden, that at least do not contradict their findings.

In the regressions presented in Tables 5 and 6, whether FDI is conducted for vertical and horizontal FDI purposes is not distinguished. Perhaps the share of vertical FDI for Swedish MNEs is relatively low, so its effects on tasks' wage-bill share vanish when vertical and horizontal activities are aggregated. In BEM, where German data is used, it is possible that the share of vertical FDI is higher than for Swedish MNEs; given the locational advantage German plants have in terms of market access to most European markets. However, BEM cannot identify whether FDI is vertical or not, so it is difficult to know whether horizontal or vertical activities drive the results.

5. Concluding Remarks

Using a unique linked employer-employee data set for Swedish MNEs in the manufacturing industry, I study the relationship between offshoring and the onshore task

[19] They proxy offshoring as the share of imported intermediate goods in total sales, without any distinction between horizontal and vertical FDI.. So what they conclude is that "imports of intermediate goods from other high income countries appear to substitute for more advanced job tasks"

composition. I find a statistically negative, although relatively small coefficient of horizontal offshoring in regressions of the wage-bill share of non-routine and interactive tasks. The relationship between horizontal FDI-offshoring and these wage-bill shares seems to be negative, which is somewhat surprising. Although some empirical evidence for the case of Sweden shows that this result is not unique to this study (see Hakkala, Heyman and Sjöholm, 2010), it does not seem to find theoretical support in the existing literature. There are two mechanisms, however, that may help explain the result.

1) The *"McDonalds hypothesis"*. Former McDonalds CEO, Ray Kroc once said that *"I put the hamburger on the assembly line"* and even though the menus cater to local tastes, it would probably be easy for a McDonalds' employee to produce burgers in any McDonalds franchise around the world. The need for common standards of communication across plants operating in different markets may drive MNEs to increase the share of codified tasks and rules that can easily be translated and performed in different locations. There are potential benefits from standardization if an employee can perform the same task in several different plants and markets and MNEs might, therefore,decrease its share of interactive and non-routine tasks parallel to its expansion. The negative correlation between horizontal FDI and the wage-bill share of interactive and non-routine tasks is perhaps just capturing the fact that the MNE is expanding, and the whole organization is experiencing a shift towards more streamlined methods of production. This phenomenon is not exclusive to low-skilled works as work practices in consulting firms, like McKinsey, for instance, where *"consultants work in different teams across spatial distance"*[20] demand streamlined work practices.

2) The *"Fixed-Cost Hypothesis"*. MNEs producing for export usually incur fixed costs associated with product adaptation to local markets' specifications and other fixed costs associated with marketing and logistics. These activities are categories skilled-labor intensive and non-routine and interactive intensive according to the task classification used in this paper. When a MNE expands and starts production offshore for market access, it is likely that many of those beachhead activities that were previously conducted onshore are now more efficiently performed in the destination market. That would change the task composition at home decreasing the share of interactive and non-routine tasks. Although appealing, more rigorous tests of these hypotheses are left for future research.

[20] See Ambos and Schlegelmilch (2009). See also Kunkel and Neumann (2003) that study both production and services MNEs. They find that *"companies that excel at cutting their overhead costs focus on harmonizing the factors they can control. The first step is often surprisingly simple: to give the same name to identical processes that have different names in different places. A second and more onerous task is to ensure that enterprise resource planning systems are integrated, which among other things allows legacy or national systems to exchange information smoothly(...)"*

It is also possible that workers with characteristics that make them especially apt for routine and non-interactive tasks, which are more easily offshored, are relatively abundant in Sweden compared to its typical horizontal offshore destination. That comparison has not been carried out here, although it would be somewhat surprising, given that Sweden is relatively abundant in highly educated workers. However, if that were the case, it would make sense shift non-routine and interactive work offshore. On the other hand, in that case one would expect a similar relationship between offshoring and the wage-bill shares of non-routine and interactive tasks when focusing on vertical FDI. For vertical FDI, however, none of the specifications produces any statistically significant results.

TABLE 9. Offshoring and the Wage-Bill Share of White Collar Occupations

	(1)	(1)	(2)	(4)	(5)
Variable	Total	By Type	By Type 2	By Income	By Region
firm relative wage	0.0084	-0.0028	-0.0011	0.0049	0.0036
	(0.013)	(0.012)	(0.012)	(0.013)	(0.014)
industry relative wage	0.6536***	0.7010***	0.7029***	0.6630***	0.6590***
	(0.105)	(0.114)	(0.105)	(0.117)	(0.122)
log Cap/Turnover	-0.1089	-0.1070	-0.0716	-0.0532	-0.0505
	(0.069)	(0.084)	(0.083)	(0.069)	(0.076)
log Turnover	-0.0294*	-0.0323**	-0.0292*	-0.0350**	-0.0390**
	(0.015)	(0.014)	(0.016)	(0.016)	(0.016)
R&D/Output	0.0672	0.4462***	0.6119***	0.7743***	1.0896***
	(0.480)	(0.145)	(0.193)	(0.265)	(0.387)
year= 1999	0.2817*	0.2715*	0.2595	0.3172*	0.3438**
	(0.144)	(0.144)	(0.157)	(0.163)	(0.165)
Share of Offshore Employment	-0.1182				
	(0.336)				
Offshore Employment in Horizontal[a] FDI		-0.0658			
		(0.145)			
Offshore Employment in Vertical[b] FDI		0.5402*			
		(0.315)			
Offshore Employment in Horizontal 2[c] FDI			0.0221		
			(0.148)		
Offshore Employment in Vertical 2[d] FDI			1.1784		
			(1.453)		
Share of Employment in HI countries				0.0412	
				(0.118)	
Share of Employment in LI countries				0.8466**	
				(0.396)	
Share of Employment in WE countries					-0.0016
					(0.214)
Share of Employment in OIC countries					0.4245**
					(0.561)
Share of Employment in EE countries					0.2756
					(0.742)
Share of Employment in ODC countries					1.0728**
					(0.377)
Observations	252	220	220	252	252
Number of unique plants	126	110	110	126	126
Adjusted R^2	0.527	0.523	0.515	0.542	0.544

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

High income (HI), Low Income (LI),Western Europe (WE), Other Industrialized Countries (OIC),

Eastern Europe (EE) and Other Developing Countries (ODC

[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).

[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets.

[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets (except Sweden).

[d]Share of total employment in offshore locations producing for exports to Sweden.

6. Appendix

TABLE 10. Offshoring and the Wage-Bill Share of Non-routine Tasks (Whole Sample)

Variable	(1) Total	(2) By Income	(3) By Region
firm relative wage	0.2333	0.2933	0.3274
	(0.280)	(0.282)	(0.289)
industry wage-bill share	0.6430***	0.6540***	0.6538***
	(0.109)	(0.110)	(0.106)
log Cap/Turnover	-0.0304***	-0.0297***	-0.0282**
	(0.011)	(0.010)	(0.011)
log Turnover	-0.0159**	-0.0184***	-0.0190***
	(0.006)	(0.006)	(0.006)
R&D/Output	0.4206*	0.4517**	0.4499**
	(0.217)	(0.214)	(0.189)
year= 1999	0.1370**	0.1596**	0.1684***
	(0.054)	(0.059)	(0.061)
year= 2003	0.1444***	0.1652***	0.1737***
	(0.049)	(0.054)	(0.054)
Total Offshoring	-0.0570		
	(0.069)		
Share of Employment in HI countries		-0.0816	
		(0.051)	
Share of Employment in LI countries		0.1374	
		(0.131)	
Share of Employment in WE			-0.0363
			(0.061)
Share of Employment in OIC			-0.2484**
			(0.098)
Share of Employment in EE countries			0.0587
			(0.252)
Share of Employment in ODC countries			0.2325*
			(0.138)
Observations	368	368	368
Number of unique plants	156	156	156
Adjusted R^2	0.373	0.383	0.391

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC), Eastern Europe (EE) and Other Developing Countries (ODC).

TABLE 11. Offshoring and the Wage-Bill Share of Interactive Tasks (Whole Sample)

Variable	(1) Total	(2) By Income	(3) By Region
firm relative wage	0.7670***	0.7728***	0.7737***
	(0.237)	(0.240)	(0.242)
industry wage-bill share	0.9524***	0.9717***	0.9711***
	(0.165)	(0.160)	(0.161)
log Cap/Turnover	-0.0095	-0.0092	-0.0093
	(0.007)	(0.007)	(0.007)
log Turnover	-0.0104***	-0.0108***	-0.0107***
	(0.003)	(0.004)	(0.004)
R&D/Output	0.0795	0.0732	0.0447
	(0.085)	(0.077)	(0.096)
year= 1999	0.0757**	0.0801**	0.0804**
	(0.031)	(0.033)	(0.034)
year= 2003	0.0605**	0.0663**	0.0674**
	(0.027)	(0.030)	(0.030)
Total Offshoring	-0.0316		
	(0.037)		
Share of Employment in HI countries		-0.0313	
		(0.030)	
Share of Employment in LI countries		0.0126	
		(0.061)	
Share of Employment in WE countries			-0.0235
			(0.037)
Share of Employment in OIC countries			-0.0721
			(0.065)
Share of Employment in EE countries			0.0539
			(0.141)
share of empl in ODC countries			0.0022
			(0.065)
Observations	368	368	368
Number of unique plants	156	156	156
Adjusted R^2	0.335	0.336	0.335

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC) Eastern Europe (EE) and Other Developing Countries (ODC).

Table 12. Vertical and Horizontal Offshoring and the Wage-Bill Share of non-routine Tasks (Whole Sample)

Variable	(1) By Type	(2) By Type 2	(3) No firm relative wage
firm relative wage	0.1256	0.1283	
	(0.326)	(0.289)	
industry wage-bill share	0.5153***	0.5311***	0.5104***
	(0.124)	(0.123)	(0.117)
log Cap/Turnover	-0.0372*	-0.0377*	-0.0359*
	(0.020)	(0.020)	(0.020)
log Turnover	-0.0195**	-0.0177*	-0.0186***
	(0.008)	(0.009)	(0.007)
R&D/Output	0.3137	0.4608**	0.3158*
	(0.187)	(0.207)	(0.182)
year= 1999	0.1771**	0.1722**	0.1712**
	(0.075)	(0.078)	(0.067)
year= 2003	0.1775**	0.1694**	0.1766**
	(0.069)	(0.077)	(0.068)
Offshore Employment in Horizontal[a] FDI	-0.1896***		-0.1889***
	(0.055)		(0.054)
Offshore Employment in Vertical[b] FDI	0.0777		0.0848
	(0.151)		(0.137)
Offshore Employment in Horizontal 2[c] FDI		-0.1694**	
		(0.064)	
Offshore Employment in Vertical 2[d] FDI		1.0200	
		(0.938)	
Observations	243	243	243
Number of unique plants	115	115	115
Adjusted R^2	0.362	0.356	0.364

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.,
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC),
Eastern Europe (EE) and Other Developing Countries (ODC).
[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).
[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets.
[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets, excluding Sweden (less restrictive measure).
[d]Share of total employment in offshore locations producing for exports to Sweden.

Table 13. Vertical and Horizontal Offshoring and the Wage-Bill Share of Interactive Tasks (Whole Sample)

Variable	(1) By Type	(2) By Type 2	(3) No firm relative wage
firm relative wage	0.4521	0.4949*	
	(0.285)	(0.288)	
industry wage-bill share	0.6596***	0.6664***	0.5416**
	(0.197)	(0.190)	(0.200)
log Cap/Turnover	-0.0151	-0.0137	-0.0179*
	(0.011)	(0.011)	(0.010)
log Turnover	-0.0115**	-0.0121**	-0.0098**
	(0.004)	(0.005)	(0.004)
R&D/Output	0.0241	-0.0143	0.1341***
	(0.084)	(0.109)	(0.043)
year= 1999	0.1040**	0.1111**	0.0898**
	(0.043)	(0.046)	(0.040)
year= 2003	0.0913**	0.0978**	0.0937**
	(0.040)	(0.043)	(0.040)
Offshore Employment in Horizontal[a] FDI	-0.1125***		-0.1087***
	(0.033)		(0.035)
Offshore Employment in Vertical[b] FDI	-0.0290		0.0032
	(0.087)		(0.073)
Offshore Employment in Horizontal 2[c] FDI		-0.1005***	
		(0.031)	
Offshore Employment in Vertical 2[d] FDI		-0.2671	
		(0.469)	
Observations	243	243	243
Number of unique plants	115	115	115
Adjusted R^2	0.301	0.296	0.273

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC), Eastern Europe (EE) and Other Developing Countries (ODC).
[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).
[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets.
[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets excluding Sweden (less restrictive measure).
[d]Share of total employment in offshore locations producing for exports to Sweden.

Table 14. Horizontal and Vertical Offshoring and the Wage-Bill Share of White Collar Occupations (Whole Sample)

Variable	(1) Total	(1) By Type	(2) By Type 2	(4) By Income	(5) By Region
firm relative wage	0.0068	-0.0047	-0.0038	0.0074	0.0069
	(0.012)	(0.010)	(0.010)	(0.013)	(0.013)
industry relative wage	0.6742***	0.7073***	0.7140***	0.6666***	0.6665***
	(0.081)	(0.107)	(0.102)	(0.087)	(0.087)
log Cap/Turnover	-0.0784***	-0.0757**	-0.0719**	-0.0790***	-0.0784***
	(0.024)	(0.035)	(0.035)	(0.024)	(0.024)
log Turnover	-0.0275**	-0.0333**	-0.0324*	-0.0315**	-0.0323**
	(0.013)	(0.014)	(0.016)	(0.014)	(0.014)
R&D/Output	0.3324	0.4235***	0.4723**	0.5313**	0.5535**
	(0.233)	(0.130)	(0.214)	(0.209)	(0.259)
year= 1999	0.2590**	0.2827*	0.2889*	0.2992**	0.3088**
	(0.127)	(0.142)	(0.152)	(0.135)	(0.142)
year= 2003	0.2722**	0.2900**	0.2967**	0.2982**	0.3068**
	(0.112)	(0.125)	(0.135)	(0.115)	(0.121)
Share of Offshore Employment	-0.0150				
	(0.147)				
Offshore Employment in Horizontal[a] FDI		-0.0641			
		(0.104)			
Offshore Employment in Vertical[b] FDI		0.3590			
		(0.228)			
Offshore Employment in Horizontal 2[c] FDI			-0.0140		
			(0.109)		
Offshore Employment in Vertical 2[d] FDI			0.5360		
			(1.465)		
Share of Employment in HI countries				-0.0582	
				(0.075)	
Share of Employment in LI countries				0.3845*	
				(0.204)	
Share of Employment in WE countries					-0.0386
Share of Employment in OIC countries					-0.1360
Share of Employment in EE countries					0.2726
Share of Employment in ODC countries					0.4512
Observations	368	243	243	368	368
Number of unique plants	156	115	115	156	156
Adjusted R^2	0.568	0.545	0.539	0.574	0.572

Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.
High income (HI), Low Income (LI), Western Europe (WE), Other Industrialized Countries (OIC), Eastern Europe (EE) and Other Developing Countries (ODC).
[a]Share of total employment in offshore locations producing for sales to its own market (restrictive measure).
[b]Share of total employment in offshore locations producing for exports to Sweden and other offshore markets
[c]Share of total employment in offshore locations producing for sales to its own and other offshore markets (except Sweden).
[d]Share of total employment in offshore locations producing for exports to Sweden.

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